Cooking fuels' choice, women's health and CO_2 emissions in rural West Africa

Aklesso Y. G. Egbendewe[1]*, Yevesse Dandonougbo[2]

[1]Department of Economics, Faculty of Economics and Management Sciences (FASEG), University of Lomé, Lomé, Togo. 01 BP 1515, Tel: (+228) 92004093, Fax: (+228) 22 51 49 51

[2]Department of Agricultural Economics and Rural Sociology, School of Agronomy (ESA), University of Lomé, Lomé, Togo, Email: ydandonougbo@gmail.com

*Corresponding author: emaklesso@gmail.com

Selected Paper prepared for presentation at the 2022 Agricultural & Applied Economics Association Annual Meeting, Anaheim, CA; July 31-August 2

Cooking fuels' choice, women's health and CO_2 emissions in rural West Africa

Abstract

This research studies the drivers of rural households' cooking fuels' choice and effects on women's health as well as on environmental quality in selected West African countries. To that end, parametric and semiparametric econometric models have been specified and estimated using dataset from surveys of 1,000 rural households in Senegal and 650 in Togo. The results suggest that firewood and charcoal are normal goods and complementary energy sources of rural households while both sources are substitutes with liquified petroleum gas (LPG). Also, the use of firewood may increase the likelihood of health issues among women as well as respiratory, skin and eyes diseases among other households' members. A Further analysis reveals a nonlinear U-inverted relationship between CO_2 emissions from solid fuels' combustion and households' income. Implied thresholds above which increased income reduces the use of solid cooking fuels are computed. The study recommends policies aiming at improving rural households' income above critical levels and increasing access to modern cooking fuels to improve rural well-being and environmental quality.

JEL classifications : C61, D13, Q12, Q15

Keywords: Cooking energy; women's health; environmental Engel curve; rural households

1. **Introduction**

The use of solid fuels for cooking continues to be frequent around the world, despite being a leading cause of morbidity in women and children (IEA, 2018 ; Gould & Urpelainen, 2018). Indeed, indoor air pollution caused by cooking fuels' combustion is one of the forms of negative externalities analyzed in the economic theory. These externalities generally generate major social costs related to not only households' health status but also to forest resources and environmental degradation (Ramanathan & Carmichael, 2008). These social costs are generally not integrated by households into the decision-making process during the choice of fuels for cooking (Finnell, et al., 1990). Nonetheless, these social costs could cause significant reductions in the well-being of the household's members and the society as a whole. Thus, being generally responsible for most of the household's activities spanning from collecting firewood (and often making charcoal) to cooking meals, women in developing countries (often accompanied by their children) are generally more exposed to cardiovascular, respiratory and nervous system health risks due to long time exposures to smoke during cooking fuels' combustion (Johnson & Chiang, 2015).

In the literature, factors such as cooking fuels used in the household, women's prior physiological conditions, the level of concentration of pollutants, income levels and the duration of exposure determine the impacts of the use of cooking fuels on human health (Fazlzadeh, et al., 2015). Yet, one of the main indoor sources of air pollution in developing countries is the use of solid biomass fuels in inefficient traditional stoves (Balakrishnan, 2018). The combustion of solid biomass releases a toxic mixture of pollutants consisting of particles such as carbon monoxide (CO), nitrogen and sulfur oxides (NOx, SOx), and carbon dioxide (CO_2) that may cause health damages (Ravindra, et al., 2020). Therefore, some researchers have demonstrated that improved stoves could reduce health risks and greenhouse gas emissions from the combustion of solid cooking fuels (Mortal, et al., 2018). Indeed, deforestation resulting from the extensive use of solid fuels is also one of the factors contributing to global warming. Forests act as natural filters that absorb carbon dioxide from the atmosphere. They store more carbon than they release and are seen as CO_2 sinks in their natural state (Haghipour & Burg, 2014). Thus, cutting down trees to make firewood and charcoal contributes doubly to global warming if not included in an optimal forest logging strategy.

While the existing literature establishes a causal link between the use of solid cooking fuels, women's health and global warming; factors that determine household access and use of these sources of cooking energy are still worth of investigation. Indeed, a proper understanding of these factors could allow appropriate measures to be taken to reduce their use in order to improve rural household's health risks and protect the environment. For several decades, access to energy in all its forms has been a fundamental element for the well-being of populations. Its use and management are the subject of a current debate. In developing countries where the majority of the population resides in rural dwellings, the limited and unreliable access to modern cooking fuels and the relatively high cost of these are generally the main causes of the use of solid fuels (Behera, et al., 2015; Das, et al., 2014). Thus, Behera et al. (2015) have shown that the use of firewood, charcoal and other wood derivatives is predominant among low-income households, while wealthier households tend to use modern energy sources for cooking, such as liquefied petroleum gas (LPG). In addition, other studies in the literature have revealed that households in developing countries typically face socio-economic, cultural and environmental barriers that prevent them to moving from traditional cooking energy consumption habits toward modern fuels (Das, et al., 2014).

In West Africa where the production of firewood is expected to exceed 50 million tons by 2030 (FAO, 2015), two countries therein (Togo and Senegal) are the subject of this research. Togo is ranked by the World Bank as a low-income country with a per capita GDP of

$614.85. This country is characterized by a Sudanese tropical climate with large forest areas contributing to abundant production of solid fuels. According to its National Institute of Statistics, Economic and Demographic Studies (INSEED, 2015); 50.4% of Togolese households use firewood and 40.2% use charcoal as cooking fuels. Most households living in rural areas use firewood for cooking (86.9%), while urban households mainly use charcoal (71.4%) for cooking (INSEED, 2015). In contrast, Senegal is ranked by the World Bank as a low middle-income country with a per capita GDP of $1,547. It has a Sudanese tropical climate in the south and a Sahelian climate in the north. As a consequence, rural populations in Senegal use more of animal wastes as a source of cooking fuels which entail various types of health consequences. According to a survey (EDS, 2015), 93% of Senegalese households use solid fuels in rural areas compared to 47% in urban areas for cooking. With regard to the emissions generated by the use of solid fuels, sub-Saharan Africa is the source of one third of the global emissions related to woody fuels' combustion, or 0.3 to 0.8 billion tonnes of CO_2 equivalent per year, including 320 million tons of CO_2 equivalent for West Africa (FAO, 2017).

The objective of this research is therefore to analyze the drivers of cooking fuels' choice and the risks that these choices pose to women's health and environmental degradation in selected rural West African countries. Specifically, this research aims at (1) determining factors that govern the choice of fuel types at the rural household level and (2) measuring the effects of the use of these fuels on women's health and 3) assessing the implications of the use of solid biomass as a cooking fuel on CO_2 emissions into the global environment. Therefore, the fundamental research question that this paper seeks to address is: what are the factors that govern rural households' cooking fuels' choices and the impact of these choices on female health and environmental risks in selected West African's countries? It thus contributes to the existing literature at three levels. First, it serves to examine trends and patterns of household energy choices, their consumption intensities and their spending habits for different energy sources. Second, it allows investigation of the process of transition of households from solid fuels to modern fuels on CO_2 emissions from forest resources depletion (which are the main sources of greenhouse gas emissions from developing countries). In view of the health and environmental effects noted in the literature and in several countries around the world (Jeuland & Pattanayak, 2012), there is still a lack of studies on this subject on the African continent. Third, this study contributes to the quest for adequate public policies aiming at reducing environmental degradation and improving women's and children's health risks in Africa. It does so by adopting a broad normative framework, that is, the energy justice framework based on the capability approach (Sovacool, et al., 2016).

The remainder of the paper is presented as follows. The second section presents the materials and methods used to study the factors that govern the access to cooking fuels as well as the effects of these on health and environmental degradation. This section also explains the research methodology and the data used for the study. The results and discussions are presented in the third section. Finally, the last section presents the conclusion and the implications for public policy.

2. Materials and methods

This section first outlines the theoretical modeling framework that underpins empirical developments in the estimation of solid fuel demand, health demand and environmental effects related to the use of solid fuels. Subsequently, it highlights econometric estimation challenges (notably that of endogeneity) that arise in assessing the effects of solid fuels' combustion on women's health and the robustness of the estimated coefficients based on the single-index semiparametric methods (Li & Racine, 2007) . Furthermore, the issues of nonlinearities related to the estimation of the so called the environmental Engel curve are addressed through the use of partially-linear semiparametric estimation methods (Yatchew, 2003; Wood, 2006). Finally, the summary statistics of the data used in the econometric regression are presented with some descriptions.

2.1. *Theoretical Model*

The theoretical model draws on the study by Edwards & Langpap (2012) to consider a model of health production of members of a representative household that derives its utility from the consumption of a market good *m*, a good *e* (such as food) produced by the household using energy inputs, *w*, and health inputs of the *n* household members ***h*** = (h_1, ..., h_n). So, the utility of the household is expressed by the following function:

$$U = u\,(m, e, h; \boldsymbol{c}) \tag{1}$$

Here ***c*** stands for a vector of the household characteristics which are not explicitly modeled, but could influence the choices of the rural household. The food produced by the household requires the use of firewood or charcoal as energy inputs, *w*, and a modern energy input such as liquefied petroleum gas (LPG), *g*, so that the food production function with the household could be written as:

$$e = f\,(w) + b(g|s) \tag{2}$$

Here *s* = 1 if the household has a stove for cooking with LPG and *s* = 0 otherwise, *b* (g | 1)> 0 and b (g | 0) = 0.

The household's health depends on the quantity of firewood used and the vectors of household characteristics linked to cooking habits, or to social environment, ***l*,** such as the cooking place (which may be or not an enclosed place). The health function could then be expressed as follows:

$$h_i = h_i\,(w\,;\,\boldsymbol{l}_i\,)\,. \tag{3}$$

The combination fuel/modern stove has no direct effect on health; it only has an indirect effect through its effect on firewood consumption. The household budget constraint is determined by the income r, and the prices of the market good p_m, the wood price p_w, and the price of gas p_g, such as:

$$p_m m + p_w w + p_g g \leq r. \tag{4}$$

The household chooses the quantity of market good, firewood and modern energy that enables maximization of its utility function (1) under constraint of the energy production function (2), the health function. (3) and the budget equation (4). The utility function is assumed to be quasi-concave and all the constraints meet the qualification conditions. So, from the corresponding first-order conditions, we can determine the functions of cooking fuels demand as well as the corresponding health production functions (Edwards & Langpap, 2005). The solution to the above optimization problem yield the households demand for cooking fuels expressed as follows:

$$w_j = q(p_m, p_w, p_g, r) \tag{5}$$

The demand equation, as expressed in equation (5), could be further expressed with the vector of household characteristics $\boldsymbol{c}$. The variables in the vector $\boldsymbol{c}$ operate as demand shifters. The new demand equation for fuel j can then be expressed as follows:

$$w_j = q(p_m, p_w, p_g, r, \boldsymbol{c}) \tag{6}$$

From the fuel demand function, we can deduce the following indirect utility function that is dependent on the parameters of the optimization problem as follows:

$$V_j = v_j(p_m, p_w, p_g, r, \boldsymbol{c}) \tag{7}$$

2.1.1. Modeling drivers of cooking fuels' choice by rural households

Let's assume that a representative household *i* is facing more than one cooking fuel options, and that the indirect utility derived from each of option *j* is defined by V_{ij}. The indirect utility function could then be broken into its deterministic components such as $x'_{ij}\beta$, and stochastic components ε_{ij} *in* such a way that the indirect utility of the fuel type *j* of household *i* is expressed in the form of a random utility function as:

$$V_{ij} = x'_{ij}\beta + \varepsilon_{ij} \tag{8}$$

Here, x_{ij} represents the vector of all the explanatory variables of equation (7). McFadden (1974) has shown that if the random component is assumed to be independently distributed with the type I extreme value distribution, then the probability (p) of a given alternative to be chosen by a household is given as:

$$p = \exp\left(x_{ij}\beta\right)/\left[\sum_{h=1}^{J} \exp\left(x_{ij}\beta\right)\right], j = 1, \ldots, J \tag{9}$$

Several probabilistic choice models are often proposed to empirically estimate the effects of the covariates on the probability for a household to choose among the various cooking fuels that are available (Wooldridge, 2010) . For its convenience in carrying out empirical regressions, the multinomial logit model is the first empirical choice in empirical modeling but it suffers from the implicit hypothesis of independence from irrelevant alternatives (IIA) assumption. To relax the implicit IIA assumption of the multinomial logit estimates, several models such as the multinomial probit model are proposed (Hausman & Wise, 1978) which is used in the empirical regression of cooking fuels' choice in this paper.

2.1.2. Modeling the effects of cooking fuels' choice on health

The health function in equation (3) could be expressed as follows:

$$h_{ij} = \alpha_0 + \alpha_1 w_j + \alpha_2 x_{ij} + \mu_{ij} \tag{10}$$

Here, h_{ij} is a dichotomous indicator of the health status of household i choosing cooking fuel type j. w_j is a vector that includes a set of fuels used by the household, the vector x_{ij} represents other socio-economic variables that may influence the health status of the household members and μ_{ij} is a random error term. The empirical estimation of the health function (equation 10) requires that account be taken for the potential endogeneity the fuel types used by the household. In this paper and based on the previous literature (Edwards & Langpap, 2012), firewood is considered as potentially endogenous among the set of fuel types. This variable is endogenous because it is determined jointly with women's health status, or that of the household members. Therefore, two instrumental variables are considered as instruments for firewood in the empirical regression. These two variables are the ownership of livestock and land ownership status of the household. These instruments are well correlated with the quantity of firewood used by the household but are not correlated to the health status of the household. The Instrumental variable (IV) estimation approach is adopted in the empirical regressions. Indeed, an auxiliary regression linking the endogenous variable to the instruments is therefore expressed by equation (11) and the health function free of the endogenous bias is given by equation (12).

$$w_j = \beta_0 + \beta_1 \tilde{x}_{ij} + \varepsilon_{ij} \quad (11)$$

$$h_{ij} = \alpha_0 + \alpha_1 \widehat{w}_j + \alpha_3 x_{ij} + \mu_{ij} \quad (12)$$

Here, $\widehat{w}_j$ is the predicted value of the endogenous variable standing for the type of fuel used by the household. The vector $\tilde{x}_{ij}$ contains the control variables such as socio-demographic characteristics of the household plus the set of instrumental variables. A two-step estimation procedure is used for this purpose. Since the quantity of firewood is a continuous variable, weighted least squares is used to estimate the auxiliary regression (11) from which the adjusted firewood quantity $\hat{w}_j$ is predicted. Next, the newly predicted quantity of firewood is introduced into the health equation (12) to estimate unbiased parameters from the sample.

Since the health status of the household is a binary response variable probit or logit models are generally used in the literature (Imran, et al., 2019) to estimate equation (12). However, one of the empirically relevant shortcomings of the binary probit or logit models are the fact they rely on the assumption that the error terms follow a given distribution (which may not be correct). For that reason, alternative specifications which requires flexible distributive assumptions such as single-index semiparametric models (Horowitz & Savin, 2001) could be considered. These semiparametric models provide sound results via a more flexible specification than a parametric distribution assumption of the error term, and preserve most of the parametric models' characteristics. As of the estimators' convergence rate, a single-index semiparametric model is as accurate as a one-dimensional nonparametric model, which is crucial to avoid the so-called curse of dimensionality problem. The semiparametric estimator of Ichimura (1993) used in the empirical estimation of the effects of the correlates on the households' health status is theoretically efficient, in the sense that it reaches the semiparametric efficiency bound if the covariates are independent with the error term (Li & Racine, 2007). Some other single-index estimators such as the Klein & Spady (1993) estimator has been also estimated but the coefficients seem to be too sensitive to heteroskedastic issues in the sample.

2.1.3. Modeling the effects of cooking fuel's choice on environmental degradation

In order to take into account environmental degradation caused by the use of solid fuels, a theoretical framework of the household production model developed by Pfaff et al. (2004) is considered. This model offers the possibility to demonstrating the existence of Engel's non-monotonic environmental curves, such as the environmental Kuznets' curves but at the households' level. Indeed, this model of household production emphasizes two points: (1) the degradation of environmental elements, a by-product derived from household activities; and (2) the shift of households to the use of less polluting production inputs to reduce environmental degradation.

So, considering the work of Kumar & Viswanathan (2007), an Engel curve of the relationship between 'polluting' fuels and incomes of rural households is estimated. The model specification is given as follows:

$$q_i = \beta_1 + \beta_2 r_i + \beta_3 r_i^2 + \sum_h \alpha_h x_{ih} + \vartheta_i \quad (13)$$

Here, q_i is the quantity of CO_2 equivalent released by a household from the combustion of firewood, r_i represents the household's income, x_{ih} the control variables and ϑ_i the error term. A semiparametric specification could also be considered (Yatchew, 2003; Egbendewe & Oloufade, 2020) in estimating the income threshold beyond which the household changes fuel types from the most polluting to the less polluting fuels. The semiparametric specification also avoids the sensitivity to outliers in the estimation of the threshold values with a quadratic specification as in equation (13). The semiparametric function could be specified as:

$$q_i = s(r_i) + \sum_h \alpha_h x_{ih} + \vartheta_i \quad (14)$$

The function $s(r_i)$ is a nonparametric smooth function of households' income to be estimated. Such a specification is helpful in identifying the presence of a threshold value from the data instead of imposing it from a quadratic specification.

2.2 *Data and Sources*

The database used for this research comes from rural surveys involving two West African countries as a part of the research project named "Optimal strategies in terms of energy efficiency for low carbon production development" initiated by the firm "ECONOLER", a Canadian think thank with funding from the International Development Research Center

(IDRC) of Canada. A survey methodology harmonized between the two countries, based on a stratified two-stage random sampling design with proportional representation, made it possible to draw the sample with the assistance of the national institutes of statistics of each country. So, following a spatial distribution of the sample, the survey areas (CA) are drawn in the first degree and in the second degree; a constant number of households is drawn in each survey area. The strata are defined by the first level of administrative division of the country. The sample counts 650 households in Togo and 1,000 households in Senegal.

The information collected from rural households are based on a household questionnaire which includes questions related to the concepts of energy poverty, household capacity to cope with energy poverty, energy efficiency, energy justice, climate change, economic and social well-being, gender, and so on. The dataset therefore contains information about the characteristics of the households such as the professional status of the head of the household, the main lighting fuel, the location of the household, the income and the availability of different cooking fuels (Key variables are in Table 1). It also provides information about the gender of the "head of the household," the age of the head of the household, the number of children and adults living in the household. Concerning the main fuel sources used, the database contains information about fuels such as crop residues, animal waste, firewood, charcoal, and liquefied petroleum gas (LPG). For each of these fuels, the information in the database concerns both the choice of fuel as the main source of cooking energy and the monthly consumed quantity and the total expenditure for the main fuel. In addition, the database also contains information on health status of the household members, and the type of sicknesses identified in the household.

With regard to the data collection, the surveyors as well as the supervisors and controllers have followed training sessions. The questionnaire was run face to face with the presence of an interviewer. The collection was conducted via tablets with integrated GPS systems to locate households. The pre-test was performed in advance so that possible amendments to the questionnaire are made.

Table 1: Summary statistics of the Variables

Variables	Description	Togo			Senegal		
		Mean	Min	Max	Mean	Min	Max
Firewood quantity	Quantity of firewood consumed as a fuel by the household (in kg)	282.686	0	999.9	137.346	0	3360
Charcoal quantity	Quantity of charcoal consumed as a fuel by the household (in Kg)	14.314	0	900	11.807	0	900
LPG quantity	Quantity of LPG consumed as a fuel by the household (in Kg)	3.427	0	600	12.176	0	6000
Animal waste quantity	Quantity of animal waste consumed as a fuel by the household (in Kg)	-	-	-	8.788	0	750
Firewood price	Purchase price of firewood in LCU per kg	37.067	0	3000	48.351	0	5000
Charcoal price	Purchase price of charcoal in LCU per kg	77.474	0	4000	781.251	0	75000
LPG price	Purchase price of Liquefied petroleum gas (LPG) in LCU per kg	556.236	350	833.3333	687.384	260	3100
Energy expenditure	Total cooking energy expenditure per month in LCU	6908.30	0	50000	3781.623	0	75000
Income	Household income per month in LCU	52805.610	1000	572000	112019	1500	1500000
Main source of cooking energy							
Wood	Usage of firewood, crop residues, and woodchips	0.833	0	1	0.792	0	1
Charcoal	Usage of charcoal	0.109	0	1	0.132	0	1
LPG	Usage of liquefied petroleum gas	0.009	0	1	0.025	0	1
Animal waste	Usage of animal waste as a cooking fuel in Sahel	--	--	--	0.050	0	1
Quantity of CO_2 produced	Quantity of CO_2 produced by the household (in Kg)	880.545	2.45	3850.35	481.40	2.45	22385.17
Age	Age of the head of the household in years	46.254	19	95	51.345	18	98
Gender	Gender of the head of the household (0. Female, 1. Male)	0.818	0	1	0.841	0	1
Household Size	The size of the household	6.079	1	18	13.577	2	70
Education	Education level of the head of the household (0. illiterate, 1. Has formal education)	0.653	0	1	0.276	0	1

Table 1: Summary statistics of the Variables (continued)

Variables	Description	Togo			Senegal		
		Mean	Min	Max	Mean	Min	Max
Farmer	Main activity of the head of household (0. Other activity, 1. Farmer)	0.886	0	1	0.426	0	1
Livestock ownership	Household owns livestock	0.494	0	1	0.688	0	1
Land access	Household owns land	0.425	0	1	0.668	0	1
Distance	Monthly distance traveled to access fuel (in km)	11.497	0	90	9.322	0	100
Electricity	Household has access to grid electric power	0.176	0	1	0.313	0	1
Stove location	location of the stove in the house (0. outdoor; 1. indoor)	0.111	0	1	0.430	0	1
Savings	Household have savings	0.079	0	1	0.031	0	1
Availability	Availability of the main source of fuel	0.517	0	1	0.681	0	1
Low energy prices	Low price of the main source of fuel	0.137	0	1	0.137	0	1
Easy access	Ease of access to the main fuel source	0.283	0	1	0.142	0	1
Fuel transport	The mode of fuel transport (0. Other, 1. walking)	0.927	0	1	0.643	0	1
Ceramic stove	Household owns Ceramic stove for cooking	0.114	0	1	0.021	0	1
Improved stove	improved stove used by the household for cooking	0.092	0	1	0.208	0	1
Female disease prevalence	Female with poor health signs in the household	0.422	0	1	0.612	0	1
Respiratory disease	Members of the household with respiratory disease	0.280	0	1	0.501	0	1
Eye disease	Members of the household eye disease	0.411	0	1	0.547	0	1
Skin disease	Members of the household with skin disease	0.164	0	1	0.361	0	1
Cardiovascular diseases	Members of the household with cardiovascular disease	0.101	0	1	0.243	0	1

3. Results and discussions

The results of the drivers of rural households' fuel choice in both countries are presented first in order to understand how prices, incomes, and socio-economic factors play in the choice of a given cooking fuel in the household. Subsequently, the effects of the consumed quantities of cooking fuels on the health status of women and households' members are presented. Finally, the impacts of solid biomass (Charcoal and wood) combustion on CO2 emissions and environmental degradation are exposed. The econometric regression results are presented side by side for Togo and Senegal to compare and contrast both results.

3.1 *Drivers of rural households' cooking fuels' choice*

Table 2 shows the results of the drivers of the choice among cooking fuels respectively in Senegal and Togo based on multinomial probit estimates. In order to identify the parameters of the model, one of the cooking fuel categories must be used as the reference[1]. The estimated parameters therefore show the effect of each covariate on the probability of choosing the category under usage compared to the category of reference. Only the signs of the coefficients can be directly interpreted as the effects of each covariate on the probability of choosing a specific cooking fuel. In each of the regressions, the chi-square statistic makes it possible to conclude on the overall significance of the coefficients.

In rural Togo, the multinomial probit regression results show negative effects of firewood and charcoal prices on the likelihood of choosing firewood and charcoal respectively as primary cooking fuel. Therefore, as expected from theoretical standpoint, each cooking fuel

[1] For both countries, we have combined woody types cooking fuels into one source to finally get four cooking fuel sources. These are Firewood (to which we have added crop residues and woodchips), Charcoal, Animal waste and LPG. In Senegal, Animal waste is taken as the reference. Even though 5% of households use animal waste as the primary cooking fuel compared to LPG with 2.5% of households, we choose to use Animal waste as the reference to look closely at the households' behavior in the use of LPG. The reason is not only LPG is a future cooking fuel source in the cooking energy mix but also as a modern energy source. In Togo, given the very insignificant use of LPG and Animal waste (0.92% and 0.15% respectively) in the cooking fuel mix, we decided to combine these two sources into other sources and use them as the reference.

reacts negatively to its own price. Income is only significant in the charcoal regression but not in the firewood regression. This is due to the fact that firewood maybe often collected for free in the forest or savanna areas while charcoal is often purchased on the market place. These results are consistent with work by Ahmad & de Oliveira, (2015) which also finds that solid cooking fuels behave as normal goods but contrary to their findings that consumers substitute these types of fuels to each other based on prices. In fact, our results instead find complementarity with negative cross-prices effects in the choice of firwood and charcoal as cooking fuels. Complementarity seems to be consistent with the behavior of households in Togo where for cultural reasons and convenience both types of fuels are used as first or second energy source. Furthermore, the work by Edwards & Langpap (2005) also shows that firewood is a normal good in low-income communities but an inferior good in high-income areas. The statistically insignificance of the LPG price in the regression is related to a very low penetration rate of LPG use in the rural Togo (less than 1%). In regard to the effects of other socio-economic drivers, they all have the expected signs.

In Senegal, the coefficients of most of the various groups of variables have similar signs as the results that are obtained in Togo. The main differences between both results are that positive and statistically significant effects of LPG price is found on the likelihood of choosing charcoal as a cooking fuel. This means that both goods behave as substitutes when households could afford only one of these fuels at the time and substitute for the other when the price of the one in current use increases and vice versa (2.5 % of rural households use LPG for cooking in rural Senegal). Therefore, public policies that seek to increase access to LPG as a modern cooking fuel in rural dwellings could be achieved through subsidizing LPG prices in Senegal. Also, given that the use of LPG requires a startup cost on materials, subsiding prices would have no significant effect on rural households in Togo given the low usage rate (less than 1%).

Table 2: **Determinants of Cooking Fuels Choices (MNP estimates)**

	Togo				Senegal					
Variables	Firewood		Charcoal		Firewood		Charcoal		GPL	
	Estimated Coef	Robust S.E.	Estimated Coef	Robust S.E.	Estimated Coef	Robust S.E.	Estimated Coef	Robust S.E.	Estimated Coef	Robust S.E.
Log (firewood price)	-0.337**	(0.14)	-0.255*	(0.15)	-0.521***	(0.05)	-0.059	(0.06)	-0.227***	(0.07)
Log (charcoal price)	-0.058	(0.16)	-0.451**	(0.21)	-0.101**	(0.05)	-0.318***	(0.06)	-0.084	(0.09)
Log (LPG price)	-1.235	(0.92)	1.925	(1.58)	-0.059	(0.05)	0.179***	(0.07)	0.083	(0.10)
Log(income)	0.102	(0.15)	0.403**	(0.18)	0.182	(0.16)	0.860***	(0.20)	0.890***	(0.29)
Age	-0.008	(0.01)	-0.013	(0.01)	0.018***	(0.01)	0.008	(0.01)	0.001	(0.01)
Gender (ref. female)	-0.213	(0.35)	-1.298***	(0.42)	0.059	(0.29)	0.056	(0.32)	0.178	(0.45)
Education (ref. illiterate)	-0.080	(0.29)	0.543	(0.37)	0.401	(0.30)	0.641**	(0.32)	1.513***	(0.39)
Household Size	0.049	(0.05)	0.029	(0.06)	-0.013	(0.01)	-0.038**	(0.02)	-0.068**	(0.03)
Log(distance)	-0.172	(0.14)	-0.402***	(0.16)	-0.019***	(0.01)	-0.021**	(0.01)	-0.141**	(0.06)
Farmer (Ref. other activity)	0.133	(0.32)	-0.111	(0.42)	-0.809***	(0.26)	-1.038***	(0.28)	-0.780*	(0.45)
Livestock ownership	0.723***	(0.28)	0.294	(0.34)	-0.525*	(0.29)	-1.065***	(0.30)	-0.984***	(0.38)
Land ownership	-0.048	(0.23)	0.215	(0.29)	-0.221	(0.28)	-0.714**	(0.30)	-0.524	(0.36)
Fuel availability	0.922***	(0.26)	0.184	(0.33)	0.188	(0.25)	0.398	(0.27)	0.155	(0.34)
Electricity	-0.434	(0.28)	0.282	(0.34)						
Constant	9.897*	(5.42)	-12.009	(9.47)	2.240	(1.64)	-7.226***	(2.20)	-8.258**	(3.64)
Log-likelihood	-233.454				-427.838					
Wald χ^2-Statistics	76.33				394.41					
Probability	0.000				0.000					
Total Observations	462.000				954.000					

Robust S.E.= Robust standard Error are in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The signs of the estimated coefficients of the multinomial probit regressions are well understood in relative terms. That is, the effect of each coefficient is relative to the cooking fuel of reference. In the regression of Togo, we have combined LPG and Animal waste as the reference cooking fuel. In Senegal, we use Animal waste as the reference cooking fuel. Thus, the interpretation of the coefficients should be done with this caveat in mind.

3.2 Effects of cooking fuels' choice on women and other household members' health status

The effect of the use of solid fuels on women and other household members' health status is analyzed using parametric (probit IV estimates) and semi-parametric (single-index Ichimura's IV estimates) regressions while solving for the problem of endogenous variable's presence in the models. Thus, a two-step IV estimation method in solving the problem of firewood endogeneity in the health production equation is utilized. At the first step, an auxiliary regression of the instruments (ownership of livestock and ownership of land) with all the exogenous variables of the model on the endogenous variable (firewood) is performed. At the second step, the main regression corrected from endogenous bias (a set binary dependent variables characterizing households' health status) is estimated. The results of the auxiliary regressions are presented in the supplemental materials (Table A1) and show that the two instruments (Livestock ownership and land ownership) are statistically significant. Indeed, the quantity of firewood consumed by a household per month would increase if the household owns livestock or owns land but these variables are not directly related to the household's health status. In fact, households may collect firewood using animal traction or need to burn firewood to chase insects from livestock (particularly those who own cattle). As of the use of land ownership as an instrument, this is driven by the observation that land ownership in both countries may help households collect easily firewood on own proprieties and facilitate access to this type of fuel.

The results in Table 3 present the effects of the use of firewood and other cooking fuels on women and other household members' health status using two-step IV probit regressions for both countries. The effects of cooking fuels on women's health status as well as the prevalence of respiratory, eyes, skin and cardio-vascular diseases within the household are estimated. Subsequently, the same results are presented in Table 4 with the Ichimura's single index semiparametric estimates[2]. Given the higher performance of semiparametric single index models in predicting correct outcomes relatively to parametric probit/logit models (Li & Racine, 2007), we use the Ichimura's single index results for robustness check. Overall, the signs of the coefficients suggest that the use of firewood as a cooking fuel by households increases the likelihood for women to show poor health status in both countries. When the diseases suffered by household members are taken separately, we find that the use of firewood is positively associated with eyes and skin diseases in Togo while in Senegal; respiratory diseases, skin diseases and cardio-vascular diseases are the most associated with the use of firewood. These positive and significant effects of firewood combustion as a cooking fuel on women and household members' health status show that long-term exposure of women and other members of the households (such as children) to smoke while burning woody biomass as a cooking fuel poses serious health related risks that represent negative indoor externalities.

Charcoal is considered as safer than firewood if used properly for it releases relatively small levels of smoke when compared with the combustion of firewood. Overall, in Togo the signs of the charcoal coefficients, demonstrate that the use of charcoal decreases the likelihood for women to show poor health conditions and the members of the household to suffer skin and eyes diseases. In contrast, the use of charcoal may increase the likelihood for women health risks in Senegal, particularly for members of the household to display respiratory and cardio-vascular diseases. These mixed effects from the use of charcoal may be related to the type of stoves that are used as well as the indoor versus outdoor location of the stove. Extended use of stoves indoor may increase the likelihood of related diseases. The mixed results of the use of charcoal on women and other household members' health is confirmed by the Ichimura's single-index semiparametric regression coefficients as well.

[2] Identification of the coefficients in the semi-parametric single-index model requires normalizing the coefficient of one continuous variable to 1. The variable age of the household is therefore set to unity for identification purpose.

The use of LPG does not show any statistically significant effects on women and other household members' health risks probably due to the relatively low penetration rate of such fuel in rural Togo (less than 1%) and Senegal (less than 3%). In contrast, the Ichimura's single-index semiparametric estimates show negative effects on women's health in Togo and mixed effects on household members' health risks. Statistically significant and negative effects of the use of LPG on the likelihood of household members to report skin disease is found in Senegal but no statistically significant effect is found on women's health risks. The mixed effects found in Togo may be due to the indoor versus outdoor use of the gas stoves. The use of LPG with materials that are unsecure, could often lead to accidents and damages to some households' members

Lastly, we find that the use of animal waste as a cooking fuel may increase female health risks in Senegal, particularly skin and cardio-vascular diseases[3] within the household. These results are consistent with those of Parikh (2011) who also have showed that air pollution due to the combustion of solid biomass fuels poses health risks to women. These effects are also consistent with the signs of the coefficients from the Ichimura's estimates. The signs of the other socio-economic covariates are as expected. In particular, we find that men headed households are less likely to be exposed to cooking fuels related diseases than women headed households. In fact, cultural division of labor in Togo and Senegal (also in most rural dwellings in Africa) favor women in home cooking activities while most of men go for farming or perform activities that are physically challenging.

[3] The type of disease that a household member would suffer due to the use of solid cooking fuels, depends on the extent to which its members are exposed to smoke, to heat or both during the combustion of the solid fuels. The mixed effects are also driven by the place where the cooking activities are located within a household. The location of the cooking activities with more aeration may reduce exposure and health damages.

Table 3: Probit estimates of the Effects of cooking fuels' choice on women's health status

Variables	Togo					Senegal				
	Female health	Respiratory disease	Eye disease	Skin disease	Cardio-disease	Female health	Respiratory disease	Eye disease	Skin disease	Cardio-disease
Log (Firewood quantity)	0.276**	0.180	0.471***	0.627***	0.048	0.220*	0.167*	0.121	0.164*	0.260**
	(2.09)	(1.33)	(3.56)	(3.99)	(0.28)	(1.84)	(1.78)	(1.31)	(1.73)	(2.54)
Log (Charcoal quantity)	-0.110*	-0.059	-0.146***	-0.291***	0.026	0.079*	0.058*	0.049	0.052	0.064*
	(-1.93)	(-1.00)	(-2.58)	(-3.98)	(0.34)	(1.86)	(1.79)	(1.54)	(1.62)	(1.93)
Log (LPG quantity)	0.001	0.002	0.003	0.001	0.002	0.034	0.028	0.018	0.065	0.035
	(0.74)	(0.90)	(1.34)	(0.64)	(0.94)	(0.51)	(0.52)	(0.34)	(1.16)	(0.61)
Animal waste quantity	-	-	-	-	-	0.006**	0.002	0.002	0.003**	0.004***
	-	-	-	-	-	(2.15)	(1.56)	(1.36)	(2.52)	(3.05)
Log (income)	-	-	-	-	-	0.810	0.811	1.057	1.557	0.324
	-	-	-	-	-	(0.70)	(0.81)	(1.12)	(1.34)	(0.28)
Log(income)^2	-	-	-	-	-	-0.040	-0.046	-0.047	-0.070	-0.012
	-	-	-	-	-	(-0.76)	(-1.00)	(-1.11)	(-1.36)	(-0.23)
Log (Expenditure)	-1.050	-0.646	-0.749	-1.226	0.872	-	-	-	-	-
	(-1.10)	(-0.65)	(-0.78)	(-1.34)	(0.88)	-	-	-	-	-
Log (Expenditure)^2	0.055	0.040	0.036	0.057	-0.059	-	-	-	-	-
	(0.99)	(0.69)	(0.65)	(1.07)	(-1.03)	-	-	-	-	-
Age	0.018***	0.012**	0.021***	0.011**	0.014***	-0.009**	-0.001	0.006*	-0.000	0.001
	(3.77)	(2.51)	(4.65)	(2.02)	(2.69)	(-2.35)	(-0.22)	(1.85)	(-0.05)	(0.25)
Gender (ref. female)	-0.784***	-0.518**	-0.846***	-0.699***	0.008	-0.135	0.059	-0.075	-0.210*	-0.240*
	(-3.74)	(-2.49)	(-4.12)	(-3.07)	(0.03)	(-0.86)	(0.48)	(-0.62)	(-1.70)	(-1.83)
Household size	0.015	0.032	0.004	-0.028	-0.018	0.010	0.018**	0.021***	0.003	0.001
	(0.65)	(1.34)	(0.17)	(-1.02)	(-0.57)	(1.03)	(2.45)	(2.92)	(0.48)	(0.07)
Education (ref. illiterate)	-2.970**	-1.004	-2.218	-2.866**	-0.496	-0.858	-0.752	1.745	-2.087	-2.540
	(-2.11)	(-0.73)	(-1.64)	(-2.01)	(-0.30)	(-0.45)	(-0.52)	(1.20)	(-1.42)	(-1.63)
Farmer (ref. other professions)	-1.167***	-0.673**	-1.096***	-1.613***	-0.489	-0.020	0.108	0.075	-0.024	-0.222**
	(-3.18)	(-2.03)	(-3.04)	(-4.82)	(-1.24)	(-0.15)	(1.12)	(0.77)	(-0.24)	(-2.14)

Robust Student-t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$;

Table 3: Probit estimates of the Effects of cooking fuels' choice on women's health status (continued)

Variables	Togo					Senegal				
	Female health	Respiratory disease	Eye disease	Skin disease	Cardio-disease	Female health	Respiratory disease	Eye disease	Skin disease	Cardio-disease
Education*Farmer	0.297	0.022	0.102	0.797**	0.397	-	-	-	-	-
	(0.71)	(0.06)	(0.25)	(2.07)	(0.83)	-	-	-	-	-
Education*log(expenditure)	0.370**	0.161	0.312**	0.330**	0.010	-	-	-	-	-
	(2.37)	(1.05)	(2.06)	(2.04)	(0.05)	-	-	-	-	-
Education*log(income)	-	-	-	-	-	0.082	0.064	-0.136	0.167	0.222
	-	-	-	-	-	(0.49)	(0.50)	(-1.06)	(1.30)	(1.62)
Stove location (ref. outdoor)	0.046	-0.286	-0.322*	-0.197	-0.649*	-	-	-	-	-
	(0.26)	(-1.37)	(-1.71)	(-0.89)	(-1.93)	-	-	-	-	-
Savings	0.024	0.042	0.179	0.341	-0.167	-	-	-	-	-
	(0.12)	(0.20)	(0.87)	(1.41)	(-0.60)	-	-	-	-	-
Fuel availability	-0.214	-0.358**	-0.194	-0.691***	0.203	-	-	-	-	-
	(-1.43)	(-2.31)	(-1.31)	(-3.89)	(0.96)	-	-	-	-	-
Easy access *low price	0.985***	0.589***	0.623***	0.369*	0.856***	0.088	0.262	-0.022	-0.309	0.191
	(4.87)	(3.07)	(3.13)	(1.76)	(3.69)	(0.28)	(1.09)	(-0.09)	(-1.14)	(0.75)
Easy access	-	-	-	-	-	0.337*	-0.046	-0.053	0.134	0.051
	-	-	-	-	-	(1.95)	(-0.36)	(-0.40)	(1.03)	(0.37)
Fuel transport (ref. other than walking)	-	-	-	-	-	0.203*	0.322***	0.164*	0.249***	0.119
	-	-	-	-	-	(1.73)	(3.57)	(1.83)	(2.72)	(1.20)
Ceramic stove (Ref. other stoves)	-0.297	-0.110	-0.075	0.326	-0.259	0.255	-0.116	-0.003	0.821***	0.473
	(-1.39)	(-0.53)	(-0.36)	(1.45)	(-0.93)	(0.63)	(-0.37)	(-0.01)	(2.73)	(1.49)
Constant	3.984	1.219	1.723	4.118	-4.943	-4.475	-4.473	-6.940	-9.657	-3.759
	(0.95)	(0.28)	(0.41)	(1.03)	(-1.12)	(-0.71)	(-0.82)	(-1.35)	(-1.49)	(-0.57)
R^2	0.144	0.096	0.129	0.130	0.095	0.054	0.047	0.034	0.037	0.033
AIC	642.888	585.267	654.004	460.447	343.232	804.293	1297.775	1306.976	1239.455	1060.239
Sample size	522	526	526	526	526	608	955	955	955	955

Robust Student-t statistics in parentheses; * p < 0.10, ** p < 0.05, *** p < 0.01

Table 4: Ichimura's semiparametric estimates of the Effects of cooking fuels' choice on women's health status

	Togo					Senegal				
Variables	emale health	Respiratory disease	Eye disease	Skin disease	Cardio-disease	Female health	Respirator y disease	Eye disease	Skin disease	Cardio-disease
Age	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Log (Firewood quantity)	0.029	0.104***	0.143***	0.145***	0.012**	0.123***	0.093***	0.060**	0.348***	0.037*
	(0.03)	(6.76)	(8.06)	(8.96)	(1.98)	(6.82)	(9.78)	(2.47)	(3.41)	(1.93)
Log (Charcoal quantity)	4.421***	-0.067***	-0.033***	-0.069***	-0.010***	-0.002	0.020***	-0.015	-0.367***	0.022*
	(6.09)	(-6.86)	(-3.41)	(-5.62)	(-3.30)	(-0.31)	(4.27)	(-1.21)	(-5.21)	(1.68)
Log (LPG quantity)	-0.103***	0.002**	-0.012***	0.043***	0.001	0.026	0.013	0.042	-0.558***	0.005
	(-2.76)	(2.41)	(-9.28)	(185.18)	(1.16)	(1.25)	(1.45)	(1.63)	(-3.96)	(0.21)
Animal waste quantity	-	-	-	-	-	0.007***	0.001***	0.000	0.018***	0.003***
	-	-	-	-	-	(10.49)	(3.90)	(0.39)	(5.83)	(4.89)
Log(income)	-	-	-	-	-	0.169***	0.265***	0.342***	0.875***	0.040*
	-	-	-	-	-	(11.60)	(30.44)	(14.06)	(6.70)	(1.68)
Log(income)^2	-	-	-	-	-	-0.003***	-0.011***	-0.016***	-0.053***	-0.002
						(-3.92)	(-28.65)	(-15.15)	(-8.37)	(-1.41)
Log (Expenditure)	3.127**	-0.048***	-0.238***	-0.385***	0.128***	-	-	-	-	-
	(1.97)	(-2.47)	(-10.19)	(-14.80)	(14.97)	-	-	-	-	-
Log (Expenditure)^2	0.503***	0.002	0.014***	0.018***	-0.010***	-	-	-	-	-
	(7.38)	(1.46)	(8.29)	(12.28)	(-21.93)	-	-	-	-	-
Gender (ref. female)	-4.377	-0.188***	-0.306***	-0.122**	-0.019	-0.025	0.030*	0.098**	0.034	-0.083
	(-1.44)	(-3.41)	(-7.23)	(-2.38)	(-1.26)	(-0.53)	(1.74)	(1.98)	(0.13)	(-1.53)
Household size	0.649*	-0.036***	0.007	-0.010	-0.011***	-0.003*	0.004***	0.011***	-0.014	0.006**
	(1.66)	(-5.27)	(1.09)	(-1.00)	(-4.55)	(-1.89)	(3.49)	(3.49)	(-1.10)	(2.05)
Education (ref. illiterate)	1.223	-0.311***	-0.621***	-0.698***	-0.240***	-0.100***	-0.304***	0.683***	0.491**	-0.430***
	(0.52)	(-6.84)	(-13.04)	(-12.78)	(-17.39)	(-3.60)	(-17.76)	(18.75)	(2.12)	(-11.37)

Student-t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Ichimura's semiparametric estimates of the Effects of cooking fuels' choice on women's health status (continued)

Variables	Togo					Senegal				
	emale health	Respiratory disease	Eye disease	Skin disease	Cardio-disease	Female health	Respirator y disease	Eye disease	Skin disease	Cardio-disease
Farmer	-35.169***	-0.348***	-0.635***	-0.440***	-0.101***	-0.075***	0.030***	-0.058*	0.656***	-0.022
	(-9.57)	(-4.70)	(-8.27)	(-5.74)	(-3.68)	(-3.24)	(2.21)	(-1.69)	(3.21)	(-0.60)
Education*Farmer	4.408*	-0.022	0.121***	0.284***	0.058***	-0.025	0.030*	0.098**	0.034	-0.083
	(1.94)	(-0.55)	(2.57)	(7.63)	(5.27)	(-0.53)	(1.74)	(1.98)	(0.13)	(-1.53)
Education*log(expenditure)	-0.934***	0.074***	0.099***	0.080***	0.026***	-	-	-	-	-
	(-3.22)	(13.36)	(20.43)	(13.28)	(19.05)	-	-	-	-	-
Education*log(income)	-	-	-	-	-	0.019***	0.017***	-0.057***	0.254***	0.042***
	-	-	-	-	-	(6.36)	(11.92)	(-16.87)	(11.94)	(11.17)
Stove location (ref. outdoor)	1.840	-0.040	0.032	-0.122**	-0.016	-	-	-	-	-
	(0.67)	(-0.76)	(0.50)	(-1.99)	(-0.96)	-	-	-	-	-
Savings	10.677***	-0.027	-0.115	0.025	0.001	-0.088	0.079**	-0.064	-0.087	0.147
	(2.81)	(-0.46)	(-1.48)	(0.26)	(-0.01)	(-0.68)	(2.56)	(-0.87)	(-0.18)	(1.34)
Fuel availability	-9.503***	-0.070*	-0.069*	-0.085*	0.056***	-	-	-	-	-
	(-4.08)	(-1.89)	(-1.88)	(-1.84)	(4.09)	-	-	-	-	-
Fuel access*low price	-3.795	0.530***	0.356***	0.090	0.166***	0.273***	0.106***	0.054	-1.753***	-0.072
	(-1.24)	(6.83)	(5.89)	(1.29)	(4.30)	(7.35)	(5.74)	(1.13)	(-5.88)	(-1.44)
Easy access	-	-	-	-	-	0.138***	-0.010	-0.043	-0.408	-0.017
	-	-	-	-	-	(3.24)	(-0.51)	(-1.01)	(-1.40)	(-0.35)
Transport by foot	-	-	-	-	-	0.029	0.062***	0.061*	-0.188	0.106
	-	-	-	-	-	(0.79)	(4.25)	(1.83)	(-0.91)	(2.47)
Ceramic stove	-2.859	-0.066	-0.058	0.049	0.013	0.003	-0.029	-0.052	0.770	-0.002
	(-0.72)	(-1.32)	(-1.01)	(0.83)	(0.94)	(0.04)	(-0.49)	(-0.32)	(1.22)	(-0.01)
R^2	0.1375	0.4842	0.4973	0.4011	0.5887	0.3679	0.3477	0.2262	0.1289	0.2345
Sample size	522	526	526	526	526	608	955	955	955	955

Student-t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.3 Effect of the use of solid fuels on environmental degradation

We estimated environmental Engel curves similar to the environmental Kuznets curve but at the households' level using parametric and semiparametric methods. Thus, Table 5 presents the results of the regression of the quantity of CO_2 emitted by households during the combustion of solid cooking fuels on a quadratic income function of households as well as other control variables using Weighted Least Square (WLS) regression. The analysis of the results reveals in both countries that the coefficients of the linear and squared terms of income are significant and have opposite signs. That is, there are non-linear relationships between households' income and the quantity of CO_2 emitted into the atmosphere through the combustion of solid cooking fuels. Thus, an increase in households' income leads to an initial increase of solid biomass use as cooking fuels, which generates significant emissions of CO_2 into the atmosphere, but after a given threshold, the increase in households' income enables substitution of solid fuels with other types of modern fuels (notably LPG) which release less CO_2 into the atmosphere.

Furthermore, it is observed that the use of improved stoves affects negatively the CO_2 emitted through combustion of solid fuels. That is, the adoption of improved stoves by households would increase energy efficiency during combustion and reduce CO_2 emissions. In addition, the increase in firewood and charcoal prices affects negatively the quantity of CO_2 released meaning that high prices of firewood and charcoal discourages the consumption of these fuels, thus leading to a reduction of CO_2 emissions. However, we observe that by increasing LPG price, the amount of CO_2 released increases meaning that households would substitute LPG to solid fuels if the price of LPG falls, which would also reduce the quantity CO_2 released into the atmosphere. To test the robustness of our results, we proceeded with a semiparametric model specification in which it is assumed that the income function is unknown and evolves nonparametrically. The results of the semiparametric component

(Table 5) present coefficients whose signs and significance are similar to those obtained by the WLS regression. The nonparametric results are shown in the form of CO_2 emissions-income graphs similar to the Kuznets' environmental curve in Figure 1. The graphs show nonlinear relationships between income and CO2 emissions during the combustion of solid fuels. Therefore, there exist average income thresholds above which households may switch from the use of solid cooking fuels to modern sources such LPG[4]. The comparison of the Akaike information criteria (AIC) statistics highlights the robustness of the semiparametric estimates.

Table 5: Estimates of the environmental Engel curves (Dependent variable: CO_2 emitted)

Variables	Togo		Senegal	
	WLS	Semi-parametric	WLS	Semi-parametric
Income	4.9926***		3.0504***	
	(4.17)		(3.35)	
Income²	-0.0084**		-0.0068***	
	(-2.43)		(-2.70)	
Age	0.4179	-0.301	-0.2804	0.633
	(0.24)	(-0.25)	(-0.23)	(0.35)
Gender (ref. Female)	-43.6903	47.142	46.7984	-31.474
	(-0.70)	(1.00)	(1.20)	(-0.44)
Household Size	37.6102***	6.853**	7.0837**	36.601***
	(3.46)	(2.55)	(2.39)	(3.65)
Improved stove	-440.6430***	-281.303***	-286.0980***	-429.133***
	(-5.57)	(-6.91)	(-7.91)	(-4.87)
Firewood price	-3.2267***	-0.182**	-0.1834*	-3.182***
	(-4.89)	(-2.26)	(-1.88)	(-5.24)
Charcoal price	-0.3242***	-0.040***	-0.0397***	-0.300**
	(-4.12)	(-3.65)	(-3.55)	(-2.07)
LPG price	0.1031	0.269***	0.2697***	0.121
	(0.66)	(3.85)	(2.66)	(0.95)
f(income)		5.78***		2.129***
Constant	589.9554***	257.146***	31.3352	791.370***
	(5.27)	(2.96)	(0.31)	(6.51)
AIC	7809.36	7805.72	9413.93	9410.89
R^2	0.18	0.18	0.16	0.14
F-Statistics	13.98	5.92	11.29	5.12
Probability	0.00	0.00	0.00	0.00
Sample size	501.00	501.00	626.00	626.00

[4] More research is needed to show whether the switch from solid cooking fuels to modern fuels such as LPG yields or not better environmental outcomes. Meanwhile, it is certain that the switch to modern sources of cooking fuels may bring more health benefits to the household and save time used in the collection of solid fuels (allocate this time for other productive activities or leisure) and reduce indirect costs due to medical expenses induced by poor health status caused by the combustion solid fuels.

WLS: Weighted Least Square

Based on the graphs shown in Figure 1, the income thresholds above which households switches from solid cooking fuels to modern cooking fuels are estimated and given in Table 6.

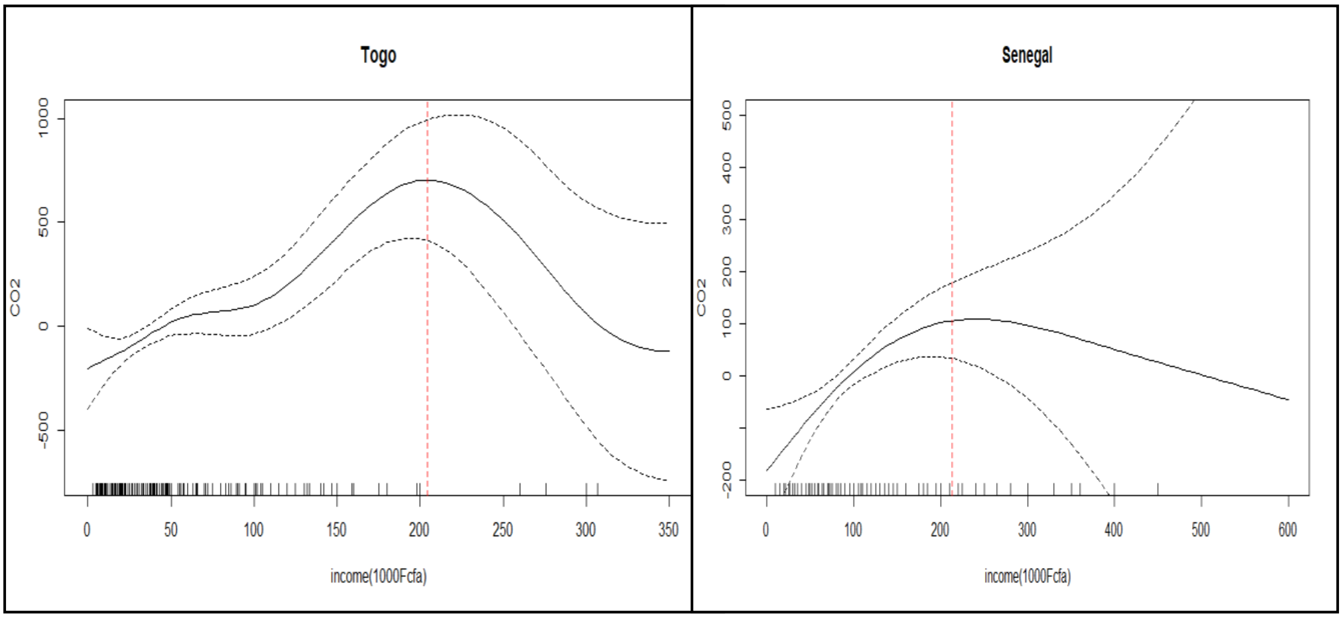

Figure 1: Nonparametric income functions plots for Togo and Senegal

Thus, for Togo, the monthly income threshold is about 204,500 LCU and 222,900 LCU for Senegal. The analysis of these results shows that there is a very large gap between the monthly households' income thresholds and the monthly income levels implied by national and international poverty lines. That is, significant increase of income levels above tpoverty lines is needed to induce a switch from the use of solid fuels to that of modern cooking fuels (such LPG) which requires startup costs to purchase stove and other materials.

Table 6: Calculation of the income thresholds and compared to the poverty thresholds

	Togo	**Senegal**
Income thresholds (optimum in LCU)	204,500	222,900
International poverty line per month in LCU (1,90$/day)	31,350	31,350
National poverty lines per monthly in LCU (2012)	22,588	18,714

The exchange rate used is $1=550F LCU

4. **Conclusion and recommendations for public policies**

This research shows that firewood and charcoal remain the main sources of cooking fuels used by rural households in the two selected West African countries. This dominance of woody biomass as a cooking fuel has been also observed by other scholars such as Karimu (2015) in Ghana and Ouedraogo (2006) in Burkina Faso. Indeed, the predominance of firewood and charcoal results from both their high availability and their affordable price. The study of the determinants of the cooking fuels' choice reveals that fuel prices, income, household size, ownership of livestock, ownership of land, fuel availability and socio-professional activities in rural dwellings are the main drivers that explain the choice of firewood or charcoal as cooking fuels. These findings also show that firewood and charcoal are normal and complementary goods in both countries but are substitutable to modern cooking fuels such as LPG if households' income rises enough (see Figure 1) or if LPG become more affordable.

Considering the effect of the use of firewood on women's health risks and that of other household members (e.g., children), the regression results show that the rise in the quantity of firewood and animal waste as primary cooking energy sources increases the likelihood of health risks among women. This result is justified by the fact that women, while spending most of their time in the kitchen, breathe pollutants contained in the smoke released by firewood for several hours a day. These fine particles of pollutants get deep into the lungs and seem to cause the most harmful effects on health. They are usually responsible for the inflammation of respiratory tracks and lungs, and can even weaken the immune system. Thus, women and household members are exposed to diseases, especially since these particles are often pending in the aerosols around their dwelling places. The more time they spend in this highly polluted environment, the more serious health consequences they will experience. In addition, women and children who spend more time indoor and near houses are the most exposed to this pollution. Moreover, it has been observed in other studies that the use of solid fuels is associated with tuberculosis, cataracts, babies born with low weight from exposed pregnant mothers, and other pathological conditions. This confirms the finding obtained in Table 3&4, that is, an increase in firewood consumption increases the likelihood of the household's members to develop respiratory, eye, skin and cardio-vascular diseases.

In regard to the environmental damages resulting from the use of solid cooking fuels, the results of descriptive statistics in Table 1 show that rural households release in the atmosphere on average 875kg and 462kg per month of CO_2 respectively in Togo and Senegal. This would result from a large number of trees being cut down for fuel. Indeed, in developing countries, in addition to the expansion of agricultural land and roads, the use of firewood and charcoal as cooking fuels contributes significantly to the increase in deforestation. It has been estimated that more than 15 million hectares of tropical forests are cleared each year for small-sized agriculture or for the use of firewood for cooking (Imran, et al., 2019). All of these contribute significantly to the degradation of the environment and amplifies global warming. However, this increased use of biomass as a source of energy is due to the very high poverty rate in these countries, and particularly in rural areas where these consumption habits are observed. Thus, a possible increase in their income levels could enable them to reduce the consumption of solid fuels in favor of more modern ones and contributing less to the degradation of the environment. From the Engel curves in Figure 1, the income thresholds estimated are still very far above the estimated rural average monthly income for many to move from solid cooking fuels to modern cooking fuels such as LPG.

The findings of this research show that increased consumption of firewood and charcoal can be reduced by improving earnings of rural households. Furthermore, given that the use of biomass as a fuel is per se a multidimensional problem which involves externalities, notably deforestation and biodiversity loss, soil erosion and loss of productivity, it would be interesting for public policies to encourage the adoption of modern cooking energy sources such as LPG as well as improved stoves in rural dwellings. Therefore, an increase in earnings via stable and remunerative activities in rural areas, or support to rural households in terms of the improvement of productivity and monetary transfers may be necessary in the short run. In addition, an increase in the prices of firewood products in favor of a decrease in LPG prices and improved stoves would also help reduce the effects of the use of biomass on rural households' health risks.

Finally, while the current debate on decarbonization is oriented towards the removal of subsidies on fossil fuels or even the increase of fossil fuels' prices through higher taxation to reduce consumption (Internation Monetary Fund, 2020), this research argues otherwise in rural West Africa and this might be the case in most developing countries. That is, the pace of decarbonization in rural dwellings (or in developing countries in general) may have to be slower to allow public policies to first work on the protection of forest resources while allowing rural households to gain progressively access to a subsidized LPG. An increase in the LPG prices would be justified only if alternative sources of clean and affordable cooking fuels become available (may be through more access to grid or off-grid electric power from greener sources such solar, wind and geothermal). These challenges call for more research on strategies towards the reduction in the use of fossil fuels in developing countries given the health risks induced by the use of biomass cooking fuels and the associated opportunity costs (Gafa, et al., 2022).

References

IEA, 2018 . *CO2 Emissions from Fossil Fuel Combustion 2018,* s.l.: International Energy Agency.

Gould, C. F. & Urpelainen, J., 2018. LPG as a clean cooking fuel: Adoption, use, and impact in rural India. *Energy Policy,* Volume 122, p. 395–408.

Ramanathan, V. & Carmichael, G., 2008. Global and regional climate changes due to black carbon. *Nature geoscience,* 1(4), p. 221–227.

Finnell, J., Kennedy, T. G. & Monk, T. E., 1990. *Evaluating Externalities Related to the Energy Sector,* s.l.: Meridian Corp. Report, prepared for PT Resource Development Consultants.

Johnson, M. A. & Chiang, R. A., 2015. Quantitative guidance for stove usage and performance to achieve health and environmental targets. *Environmental Health Perspectives,* 123(8), pp. 820-826.

Fazlzadeh, M., Rostami, R., Hazrati, S. & al, e., 2015. Concentrations of carbon monoxide in indoor and outdoor air of Ghalyun cafes. *Atmospheric Pollution Research,* 6(4), p. 550–555..

Balakrishnan, K., 2018. Fueling clean household environments. *EcoHealth* , 15(4), p. 876–877.

Ravindra, K., Kaur-Sidhu, M. & Mor, S., 2020. Air Pollution in Rural Households Due to Solid Biomass Fuel Use and Its Health Impacts. *Indoor Environmental Quality,* p. 27–33.

Haghipour, N. & Burg, J.-P., 2014. Geomorphological analysis of the drainage system on the growing Makran accretionary wedge. *Geomorphology* , Volume 209, p. 111–132.

Behera, B., Jeetendra, A. & Ali, A., 2015. Household collection and use of biomass energy sources in South Asia. *Energy* , Volume 85, p. 468–480.

Das, S., De Groote, H. & Behera, B., 2014. Determinants of household energy use in Bhutan. *Energy* , Volume 69, p. 661–672.

FAO, 2015. *Global Forest Resources Assessment 2015: How have the world's forests changed?* , Rome, Italy: FAO.

INSEED, 2015. *Questionnaire Unifié des Indicateurs de Base du Bien-Être 2015,* Lome, Togo: INSEED.

EDS, 2018. *Cinquième Enquête Démographiqueet de Santé au Bénin (EDSB-V) 2017-2018,* Cotonou Benin: Institut National de la Statistique et de l'Analyse Économique (INSAE).

EDS, 2015. *Enquête Démographique et de Santé Continue* , Dakar Sénégal: Agence Nationale de la Statistique et de la Démographie (ANSD).

FAO, 2017. *The charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods,* Rome, Italy: FAO.

Jeuland, M. A. & Pattanayak, S. K., 2012. Benefits and Costs of Improved Cookstoves: Assessing the Implications of Variability in Health, Forest and Climate Impacts. *PLOS ONE,* 7(2), p. e30338.

Sovacool, B. K., Heffron, R. J., McCauley, D. & Goldthau, A., 2016. Energy decisions reframed as justice and ethical concerns. *Nature Energy,* 1(5), pp. 1-6.

Edwards, J. H. & Langpap, C., 2005. Startup costs and the decision to switch from firewood to gas fuel. *Land Economics,* 81(4), p. 570–586.

Edwards, J. H. & Langpap, C., 2012. Fuel choice, indoor air pollution and children’s health.. *Environment and Development Economics,* 17(4), p. 379–406.

Imran, M., Özçatalbaş, O. & Bakhsh, K., 2019. Rural household preferences for cleaner energy sources in Pakistan. *Environmental science and pollution research,* 26(22), p. 22783–22793.

Horowitz, J. L. & Savin, N. E., 2001. Binary response models: Logits, probits and semiparametrics. *Journal of Economic Perspectives,* 15(4), pp. 43-56.

Klein, R. W. & Spady, R. H., 1993. An efficient semiparametric estimator for binary response models. *Econometrica: Journal of the Econometric Society,* pp. 387-421.

Pfaff, A. S., Chaudhuri, S. & Nye H, L., 2004. Household production and environmental Kuznets curves–examining the desirability and feasibility of substitution. *Environmental and Resource Economics,* 27(2), p. 187–200.

Kumar, K. K. & Viswanathan, B., 2007. Changing structure of income indoor air pollution relationship in India.. *Energy Policy,* 35(11), pp. 5496-5504.

Ahmad, S. & de Oliveira, J. A. P., 2015. Fuel switching in slum and non-slum households in urban India. *Journal of Cleaner Production* , Volume 94, p. 130–136.

Parikh, J., 2011. Hardships and health impacts on women due to traditional cooking fuels: A case study of Himachal Pradesh, India. *Energy Policy,* 39(12), p. 7587–7594.

Karimu, A., 2015. Cooking fuel preferences among Ghanaian Households: an empirical analysis. *Energy for Sustainable Development* , Volume 27, p. 10–17.

Ouedraogo, B., 2006. Household energy preferences for cooking in urban Ouagadougou, Burkina Faso. *Energy policy,* 34(18), p. 3787–3795.

Mortal, A., Aníbal, J., Monteiro, J. & al, e., 2018. *INCREaSE: Proceedings of the 1st International Congress on Engineering and Sustainability in the XXI Century.* s.l., INCREaSE 2017.

Wooldridge, M. J., 2010. *Econometric analysis of cross section and panel data.* second edition ed. Cambridge, Massachusetts: The MIT Press.

Hausman, J. A. & Wise, D. A., 1978. A conditional probit model for qualitative choice: Discrete decisions recognizing interdependence and heterogeneous preferences. *Econometrica,* 46(1), pp. 403-426.

Ichimura, H., 1993. Semiparametric least squares (SLS) and weighted SLS estimation of single-index models. *Journal of Econometrics,* 58(1), pp. 71-120.

Li, Q. & Racine, J. S., 2007. *Nonparametric Econometrics: Theory and Practice.* Princeton: Princeton University Press.

Yatchew, A., 2003. *Semiparametric regression for applied econometrician.* Cambridge: Cambridge University Press.

Wood, S. N., 2006. *Generalized additive models: An introduction with R.* London: Chapman & Hall/CRC.

Egbendewe, A. Y. G. & Oloufade, D. K., 2020. Good institutions and banking sector competitiveness: A semiparametric evidence. *Finance Research Letters,* 36(1), pp. 1-6.

Internation Monetary Fund, 2020. *World Economic Outlook: A long and difficult Ascent,* Washington, DC: IMF.

Gafa, W. D., Egbendewe, A. Y. G. & Jodoin, L., 2022. Operationalizing affordability criterion in energy justice: Evidence from rural West Africa. *Energy Economics,* 109(1), pp. 1-10.

Supplementary materials

Table A1: Auxiliary regression showing statistically significant instrumental variables (IV)

Variables	Togo		Senegal	
	Log (Firewood quantity)		Log (Firewood quantity)	
	Coef	t-stat	Coef	t-stat
Livestock ownership	**0.802*** **	**(4.51)**	**0.685*** **	**(4.61)**
Land ownership	**0.403** **	**(2.25)**	**0.619*** **	**(3.93)**
Log (Charcoal quantity)	0.359***	(9.31)	0.071	(1.53)
Log (LPG quantity)	-0.004	(-0.57)	-0.155	(-1.50)
Animal waste quantity			-0.012***	(-5.42)
Log (income)			2.263	(1.48)
Log $(\text{income})^2$			-0.116*	(-1.72)
Log (Expenditure)	-1.330	(-0.96)		
Log $(\text{Expenditure})^2$	0.105	(1.35)		
Age	-0.009	(-1.53)	0.004	(0.99)
Gender (ref. female)	0.661**	(2.56)	0.237	(1.27)
Household size	0.059**	(2.07)	0.040***	(4.99)
Education (ref. illiterate)	0.785	(0.42)	2.035	(0.95)
Farmer (ref: other professions)	0.699	(1.55)	0.166	(1.24)
Education*Farmer	-0.001	(-0.00)		
Education*Log(expenditure)	-0.170	(-0.83)		
Education*Log(income)			-0.189	(-0.98)
Stove location (ref. indoor)	-0.042	(-0.16)		
Savings	-0.449	(-1.45)	0.033	(0.08)
Fuel availability	0.521***	(2.65)		
Easy access *low price	0.037	(0.12)	-0.224	(-1.17)
Easy access			0.632***	(3.48)
Fuel transport (ref. other than foot)			-0.048	(-0.35)
Ceramic stove (Ref. other stoves)	-0.817***	(-2.65)	-0.806**	(-2.37)
Constant	6.490	(1.05)	-8.786	(-1.02)
R^2	0.273		0.219	
F-statistics	11.479		10.821	
probability	0.000		0.000	
Sample size	526.000		955.000	

Robust Student-t statistics in parentheses using weighted least squares regression; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$;