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Abstract

The aim of this paper is to examine the factors affecting households' choices of primary cooking fuels in Sudan and to indicate the likely associated side effects and the relevant policies to mitigate them. The method of investigation applied graphical, contingency tabulation and discrete choice analyses to data drawn from the recently conducted Household Health Survey. The results show that traditional solid biomass dominates the fuel-portfolio with two third of the population using smokier fuels and that deforestation and health risks, especially among small children, are the key associated externalities. It is also found that, asset poverty, low educational achievement, and female headship of households are important factors retarding the adoption of clean fuels. Other household's demographic characteristics as well as status and location of the dwelling unit also robustly influence fuel choices. Policymakers need to account for these factors in the design of action plans aiming to scale up access to clean and green fuels. The findings imply that taxing smokier fuels might not be equitable; however, a tax on selected biomass fuels and other measures could be administered to regulate biomass consumption, increase its production and improve the efficiency of its utilization with reduced risks. In addition, policies aiming at raising income and improving education would smooth the transition to modern fuels.

ملخص

تهدف هذة الورقة لفحص العوامل المؤثرة على خيارات الأُسر المعيشيِّة لوقود الطهى لأساسى فى السودان و لتحديد للآثار الجانبيَّة المرتبطة بذلك والسياسات اللاَزمة لدرئها. طَبَّقت طريقة تحليل الاشكال البيانية و الجدْولة المتقاطعة و الإختيار المُنفصل على بيانات أُخذت من مسح صحة الأُسرة الذى تمَ حديثا. أوضحت النتائج أن الكُتل الحيوية التقليدية تُهيمن على محفظة الوقود حيث يَستخدم ثُلثى السكان وقود مُنتج للدخان؛ وأن إزالة الغابات والمخاطر الصحيِة، خصوصاً بين الطفال، من الآثار الخارجيَة الأساسية المُرتبطة. وُجِد أيضاً أن إفتقار الأصول، والإنجاز التًعليمى المنخفض والرئاسة الإنثوية للأسر عواملاً مهمة تُعيق إستخدام الوقود النظيف؛ وأن الصفات الديمغرافية الأُخرى للأُسرة و مستوى الوحدة السكنيّة وموقعها أيضاً تُؤثر بقوُة على إختيارات الوقود. يحتاج صانع القرار لأخذ هذه العوامل فى الحسبان عند تصميم خطط عمل تهدف لتوسيع نطاق الوصولية للوقود النظيف والحيوى. تدل النتائج على أن فرض ضريبة على الوقود المُنتج للدخان قد لا يكون عادلا؛ لكن، يمكن إِعمال ضريبة على وقود كُتل حيوية مُختارة مع تدابير أُخرى لتنظيم إستهلاك الكُتل الحيوية وزيادة إنتاجها وتحسين كفاءة إستخدامها مع تقليل المخاطر. أيضاً، السياسات التى تهدف لزيادة الدخل و تحسين التعليم ستُمهِّد الإنتقال للوقود الحديث.

1. Introduction

The household sector in Sudan, as the case in other less developed countries (LDCs), depends on solid biomass: firewood, charcoal and residuals as main source of fuel and cash income. It is estimated that 72.4% of the households use solid biomass as primary source of energy for cooking (SHHSR 2007). Such dependence is not a problem if supply and consumption of biomass are carried out in sustainable way. However, deforestation emerged as policy issue in Sudan. The bulk of forest harvesting for biomass occurs in dry and semi-arid regions, which contain more than a quarter of the forests cover in the country (FAO 2005). The ensuing deforestation negatively affects biodiversity and leads to environmental degradation. Furthermore, the usage of crop residuals for fuel implies that they may not be available as fertilizers. This practice could undermine the very foundation of economic growth due to acceleration of soil erosion and the loss in agricultural productivity. The adoption of biomass for cooking and heating can also increasingly develop into major source of health hazards due to indoor pollution.

The patterns of biomass consumption vary by locality; for example, firewood is the main source of energy for rural households whereas urban residents more frequently use charcoal. Khartoum region alone is estimated to consume more than half the total annually produced charcoal (Pearce et al. 1990). Charcoal is typically produced in Sudan with low conversion efficiencies, which means that the wood requirements for its production are quite high. The Forest National Corporation and FAO, (FNC/FAO)'s (1995) study estimated that the conversion losses are equivalent to 61.2% of the total firewood consumption for northern Sudan.

The natural resource base consistent with sustainable consumption of biomass in Sudan needs to be determined. However, the National Forest Inventory conducted in 1995 (see NFI 1996) and the forests products demand study implemented by FNC/FAO (1995) showed that, the annual consumption of forests products far exceeds the allowable cut, signaling potential resource-scarcity curse. The FAO-Africover (2012) revealed that Sudan's forest cover shrunk by 1.6 percentage points in 2011 down from 11.6% in 2000. Sudan is also a net emitter of greenhouse gases since 2000, (see SFNC 2003), and continues to lose its forest cover. The UNEP's (2007) study found that between 1990 and 2005 the country lost 11.6% of its forest cover. Some studies even predicted an "energy crisis" in the northern Sudan (see Callaghan et al. 1985; Pearce et al. 1990). For example, Pearce et al. (1990) argued that, the stock of woody biomass is decreasing by 5.5% per year in northern Sudan and by 25 % in Kordofan, which is an important supplier of biomass. This implies that northern Sudan- with the exception of Darfur- will exhaust its wood stock by 2020. However, it should be noted that, the argument of Pearce et al. (1990) and similar reasoning in Callaghan et al. (1985), assume that biomass demand is linearly increasing and there is no price feedback.

The official response to the rising demand for biomass involves implementation of a number of policies. Firstly, the government rolled out a substantial infrastructure in clean energy aiming to increase the electrification rate from 30% to 50% through improving the existing grid services and increasing the generation capacity of Merowe Dam to produce 1250 megawatt per year. The commercial exploitation of oil since 1999 made this huge investment possible and also made other fuel alternatives like gasoline, propane and Liquefied Petroleum Gas (LPG) more accessible especially for urban dwellers. Secondly, LPG price subsidies of different design and duration are attempted to encourage a switch to more clean energy sources. Finally, many fuel-efficient stoves programs are implemented often in collaboration with international development and humanitarian aid organizations such as Cooperative Housing Foundation (CHF) International and the Intermediate Technology Development Group (ITDG).

The literature on the energy sector in Sudan is very slim; the main themes explored relate to the investigations of the macro-energy balance including the population-biomass-environment interactions, as in NFI (1996); FNC/FAO (1995); Yousif (1995) and Pearce et al. (1990). Other studies focused on the development and efficient utilization of Sudan's alternative energy potentials as in Omer (2001, 2003) as well as in Omer and Omer (2007). The possible health hazards associated with the use of firewood were explored in Hood et al. (2004).

The main objective of this paper is to analyze the factors that influence the household's cooking fuel choice in Sudan and indicate the associated potential side effects. In particular, the use of biomass fuels for cooking involves two key externalities. The first relates to deforestation and desertification with obvious implications for loss of land fertility, natural resources driven conflicts and negative greenhouse effects. The second concerns with the health hazards due to indoor pollution. Evidences on high consumption of smokier biomass would indicate low ranking on the energy services that are clean, safe, affordable and available, in addition to de-greening of the economy.

Policy interventions in the household's energy sector broadly focus on effecting demand transition from woody biomass towards modern fuels and appliances (see e.g. SFNC 2003). However, such transition to reduce the pressure on forest resources is conditioned by the adoption rate. In general, the adoption of modern fuels, such as LPG and electricity, which rank high in the clean energy services, is not only constraint by the fuel costs but also by the relatively high start-up costs of connection, the availability of cooking utensils and the stability of supply sources. Moreover, the household's traits, including initial endowment, may also influence the adoption of modern fuels. Thus, the understanding of the factors affecting the household fuel choice decisions is essential for the design of public policy aiming to stimulate clean and sustained cooking fuel energy. The following more specific questions need to be addressed in order to provide inputs relevant for designing such public policy.

Firstly, to what extents do the patterns of usage of cooking fuels vary by type of fuel as well as by economic status and location of the households, and what is the degree of seriousness of the health hazard involved?

Secondly, what are the main covariates that could have influenced fuel choices at the household level, and what are the likely environmental risks related to these choices?

The analysis relied on a two-step process corresponding to these questions. The first step focuses on the descriptive analysis of the households' fuel preferences contained in the Sudan Household Health Survey (SHHS) in order to motivate their formal modelling; it also reviews the associated health risks. The degree of health hazard due to fuel smoke is explored through the contingency tabulation of reported cases of suspected pneumonia among small children by the observed households' cooking arrangements and by income quintiles for users and non-users of smokier fuels. The second step uses a discrete choice model, coherent with the consumer theory, to examine the factors that could have influenced the household's fuel preferences in Sudan. The results of this analysis along with other relevant information on the country are used to indicate the environmental risks involved in the cooking fuels sector.

The SHHS (2006) is the first countrywide survey for Sudan in more than twenty years due to the civil war. Thus, the paper drew on updated and more improved data in terms of coverage compared to the previous literature on population-biomass in Sudan. Accordingly, the findings are generalizable countrywide.

The results showed that, traditional solid biomass continues to dominate the fuel-portfolio in Sudan with two third of population using smokier fuels. The health risks, particularly among small children, and deforestation are the key associated externalities. The percentage of children reported for suspected pneumonia infection is more than double among users of smokier fuels (69.9%) compared with non-users (30.1%). Most of these cases occur among rural children.

In addition, income growth and urbanization are found to be the main factors that induce switching out of wood towards charcoal. Over time, this trend might lead to serious deforestation resulting from pressures on the rural hinterland for charcoal production. Many factors beside income, which is emphasized in wide literature on cooking fuel adoption, are equally found important in affecting fuel choice. In particular, the demographic characteristics of the household, the educational achievements and the gender of the head as well as the status and the location of the dwelling unit robustly influence the choice of the primary fuel. Additionally, the entrenched traditional Sudanese culture of fragranced-wood-smoke for beauty treatment (*dokhan*) among adult women is predicted to raise the probability of adopting smokier fuels. All these factors jointly need to be considered for understanding the household's fuel choice behaviour and for policy design in cooking fuel sector in Sudan.

These findings suggest that, the existing policies focusing on fuel switch, while important, need to be complemented with measures aiming to increase the feedstock of the dominant fuel sources, improve the efficiency of their utilization and ameliorate the associated health and environmental risks. The results also imply that, imposing a tax on smokier fuels might not be equitable as the poor and the relatively rich are found to consume them. Instead, a tax on selected forest products could be administered to regulate biomass consumption and provide for forest sustainability. In addition, policies aiming at raising income and improving education would smooth the transition to modern fuels.

The rest of the paper is organized as follows; the next section reviews the literature. Section 3 outlines the methodology and the empirical model. Section 4 presents the study variables, the descriptive statistics, the results and the discussion. Section 5 concludes and indicates the policy implications.

2. Literature Review

Generally, the literature on energy production, consumption and the associated environmental impact in Sudan is slim though is growing over time. Most of the studies tend to focus on the macro factors affecting the aggregate energy balance; including the assessment of the population-biomass-environment link. The main concerns relate to whether demand for biomass, especially wood, exceeds sustainable supply (forest), what are the consequences of biomass deficit, and what policy can do. For example, the FNC/FAO's (1995) study examined the forest products and their aggregate demand. In addition, the National Forest Inventory NFI (1996) and Glen (1996) studied the forests endowment, their distribution and rates of utilization.

Yousif (1995) studied the patterns of biomass utilization using an energy assessment survey for the central region, which is the main consumer of biomass in Sudan. His results revealed that, biomass uses vary considerably by location and by type of the dwelling unit, where rural households tend to use firewood and residuals for cooking, while urban households opt for charcoal and LPG. Similarly, residence in poor housing conditions compared with good housing, tends to encourage the adoption of woody biomass. The main conclusion of the paper was that, the consumption of firewood and charcoal in Sudan exceeds the allowable cut by about 22,000 and 32,000 metric tons, respectively, which is an indication of serious deforestation. Callaghan et al. (1985) also reported similar conclusion for Sudan. Both studies recommended improved stoves and other energy-saving measures to increase the efficiency of biomass uses.

In the same vein, Pearce et al. (1990) drew data from various sources to study the relationships between the sustainable utilization of biomass and the socio-economic dynamics of land use pressures in Sudan. The authors identified the natural resource degradation- due to increasing biomass harvesting- as the main environmental problem especially in the densely populated areas. They concluded that, although only Khartoum and Northern states registered the highest firewood deficit, the emerging trend of woody biomass consumption in Sudan is not sustainable in the long run. The authors suggest a national approach for natural resource management as an appropriate framework to the valuation and utilization of the natural resources to achieve sustainable growth and development. Examples of other studies focusing on the development and efficient utilization of Sudan's energy potentials to reduce the dependence on woody biomass are found in Omer (2001, 2003) as well as in Omer and Omer (2007).

Hood et al. (2004) studied the health hazards of biomass using a sample of 30 households from Kassala in eastern Sudan. The standard method of indoor air quality monitoring is used. Their results revealed high levels of particulate matter and carbon monoxide; they conclude that, the high dependence on biomass fuels not only contributed to environmental degradation, but also caused health problems to women and children less than five years old. The authors recommended the scaling-up of smoke reduction intervention based on the efforts of existing woman development associations in the study area.

More generally, the biomass energy balance is widely debated in the development literature. On one hand, firewood energy crisis has been envisaged by many influential publications. See for example, Eckholm (1975), Heltberg et al. (2000) and Dewees (1989). On the other hand, Aronld et al. (2003) assessed the firewood situation worldwide and do not found enough evidence to substantiate the view that, firewood demand has been outpacing sustainable supply in a manner that makes it a major concern for deforestation. However, the use of firewood is found a matter of concern in particular areas in a country and for a particular group of users and suppliers.

This paper attempts to add to previous researches on the energy-environment nexus in Sudan. Household level data and other relevant information are deployed to review the determinants of the usage of primary cooking fuels including an indication of the associated potential externalities and what policy can do. The next section outlines the methodology and the specification of the empirical model.

3. The Methodology

The method of the analysis relied on the descriptive analysis and formal modeling of the households' fuel preferences contained in the SHHS. This two-step process corresponding to the paper's research questions is highlighted in the following subsections.

3.1. *Descriptive statistics*

The graphical and the contingency tabulation analyses are applied to review households' fuel preferences and the extent of the associated health risks. The graphs describe the patterns of the unconditional correlation between a given fuel adoption rate and selected households' characteristics in order to highlight the overall nature of fuel choices.

The health risks due to indoor pollution are explored by cross-tabulation. It is difficult to fully analyze the health hazards from biomass smoke in Sudan. However, the SHHS contains information on fuels uses, households' cooking habitat and the reported cases of suspected pneumonia among children below five years of age. This information can give an indication on the extent of indoor pollution. In general, the dwellers of a household where cooking with biomass takes place more frequently in all-purpose room, are exposed most to the risk of indoor pollution depending on the duration of cooking and quality of ventilation. Cooking in a separate room, i.e. a designated kitchen, represents an intermediate level of risk Thus, the degree of the health hazard is examined through cross tabulation of a dummy variable binning the smokier fuels, (firewood, straws, dung and crop residuals), by the reported child cases, the predominant cooking habitats and income quintile.

The nest step develops a discrete choice model of the factors that could have influenced the adoption probability of each fuel. The likely implications of these choices for deforestation along with other information on the country are used to indicate extent of environmental risks.

3.2 Discrete choice model

A structural model of demand, consistent with the theory of consumer choice, is outlined in order to highlight the assumptions leading to the empirical model. Let a representative household maximize static utility by choosing both a cooking fuel from finite set of mutually exclusive alternatives and a composite of non-fuel goods given the constraint of budget. This choice plan could be represented as follows,

$$\max_{x_f, x_n} u(x_f, x_n | \beta_h) \quad \textit{subject to } p'x'_f + x'_n \leq y, \tag{1}$$

where x'_f denotes a vector of fuel quantities, p' is a vector of prices, x'_n denotes a vector of non-fuel goods with a price of 1.0 and y is income. The utility function is indexed by the household's characteristics β_h.

The specifications of the functional form $u(.)$ and the stochastic term are needed for the empirical model. Following the generally case, the utility function is assumed positively valued, weakly separable and weakly increasing in its arguments with diminishing marginal returns. It should be noted that, the assumption of separability might not be precisely correct in this application because a large number of households in Sudan may be involved in fuel production for their own use. In addition, markets for firewood, straws and residuals fuels are largely imperfect or missing especially in rural areas. In these settings, the most important problem is the endogeneity of income or consumption due to the observation that the household decisions concerning labour supply, consumption and biomass fuel collection are made jointly. The standard agricultural household model is proposed in the literature to account for such endogeneity in the budget constant as in Heltberg et al. (2000), Amacher et al. (1993) and Gebreegziabher et al. (2010). However, the SHHS data does not contain enough information to allow full estimation of the household-farm model; hence, equation 1 is taken as the maintained structural model.

The role of weak separability assumption is to resolve the dimensionality problem of demand systems implied by equation 1 by breaking the decision making process into two parts. A decision is made first to allocate income between fuel and non-fuel goods. If non-zero income is allocated to fuel a further decision is made on how to allocate this income between fuels. Since there is only information on actual fuel purchases in SHHS, i.e. cases where the elements of x'_f are non-zeros, the utility of composite of non-fuel goods might be normalized to zero. Thus, to ensure a discrete fuel choice outcome, equation 1 is expressed into the following linear form with constant marginal utilities,

$$\max_{x_f} u(x_f \mid \beta_h) = \sum_{j=1}^{K} \alpha_j x_j; \quad \textit{subject to} \sum_{j=1}^{K} p_{fj} x_{fj} \le y_f;\ j = 1, 2, ..., K, \tag{2}$$

where, $\alpha_j \ge 0$ for all j=1,2,…,K; $\alpha_j > 0$ for at least *j* and *K* denotes the set of fuel alternatives. The utility maximizing choice of fuel, given the budget constraint, obeys the Kuhn-Tucker first order conditions, (Kuhn and Tucker 1959), and can be had by differentiating the Lagrangian from equation 2, that is;

$$\begin{aligned} &\partial u(x_f \mid \beta_h) \big/ \partial x_j = \alpha_j - \lambda p_{fj} \le 0 \ \text{ with equality if } x^*_{fj} > 0 \ \ j = 1, ..., K \\ &p_f x_f \le y_f \text{ with equality if } \lambda > 0, \end{aligned} \tag{3}$$

where x_f^* is the vector of observed optimal fuel demand, which could further be expressed as a function of income and fuel prices. The assumptions leading to this solution imply that, all fuels in the choice set are 'economic' goods. In this regard, the health side effect due to the use of smokier biomass is a 'private bad' and the associated deforestation externality is a social bad[1]. Whether such a 'lose-lose' situation could be turned into win-win scenario through a Pigovian tax requires further information on the biomass markets and consumption behavior.

From the Kuhn-Tucker conditions, which establish the basis for the economic model of discrete choice, the optimal choice solution is determined by the ratio of marginal utilities to prices among fuel alternatives independent of income allocation, (McFadden 1981). Thus, the equation does not allow switching from low to high quality fuels as a household increases spending on fuel. This is not a desirable property; particularly that the role of income in the household's energy demand has been emphasized in a wide literature. For example, the energy-ladder theory since 1980s assigned crucial role for income in the transition from low quality traditional energy sources to modern fuels and appliances (see Hosier and Dowd 1987, 1988; Smith 1987; Leach and Mearns 1988; and Leach 1992). More recently, the leapfrogging model associates energy demand with the stages of development and per capita income growth, (see Steve 2000; Goldemberg 1998).

Generally, many assumptions have been proposed in the literature on the discrete-continuous demand modeling to introduce income in the choice equation using preference structure similar to equation 1. For example, McFadden (1981) pointed that, income correlates with variables that reflect taste; and hence, it should be included in the utility function like the other socio-economic characteristics, (e.g. age, education gender etc.), which are usually included to account for

[1] Children and women are not usually involved in fuel choice decision and involuntary exposed to pollution risks, hence indoor pollution is partially external (see also WHO 2009).

differences within the population. Various studies on discrete choice modeling motivated the inclusion of income following this assumption. In this literature, income is considered as proxy for taste rather than purchasing power. However, Jara-d-Dfaz (1990) explicitly tested the presumed relation between income and taste empirically and concluded that they are unrelated. It should be noted that, this testing procedure is conducted using random utility, which implicitly assumes constant marginal utilities of alternatives. Amador and Cherchi (2009) showed that, this class of order preserving transformations could lead to misinterpretation of results. Allenby and Rossi (1991) and Allenby et al. (2008) proposed a model that explicitly allows for consumers trade-up using structural form similar to equation 1; with a bivariate utility nesting a sub-utility over the choice set with linear, but rotating indifference curves. As shown below, income is included as a conditional variable, reflecting ability to spend on fuels.

The likelihood for demand is derivable via the standard random utility, (see McFadden, 1973). The errors are usually introduced into the utility function to allow observed data to diverge from the deterministic choices implied by equation 1, i.e. in any choice occasion, the household's marginal utility may vary. Adding the errors to the maintained demand equation 2 and applying the Kuhn-Tucker conditions (3); the probability that household h will choose fuel j can be written as;

$$P_{hj} = \Pr(x^*_{hfj} > 0) = \alpha_{hj} - \lambda p_{hfj} + \varepsilon_{hj} > \alpha_{hk} - \lambda p_{hfk} + \varepsilon_{hk} \ \text{ for all } j \neq k \tag{4}$$

By substituting the marginal utilities errors into the demand relation; the vector of observed optimal demand, $d^* = x^*$, is then a function of the marginal utility given p_f and y_f, which can be expressed as; $d^* = f(\varepsilon | \beta_h, p_f, y_f)$. Generally, for K choice options the errors span a K dimensional space, and regions of that space map onto the condition that the ratio of price to marginal utility is maximized (see Chandukala et al. 2007, Rossi and Allenby 2009). If the errors are independent and identically distributed over each fuel, then the choice probabilities can be written in terms of integrals of the cumulative distribution functions of errors, (suppressing the household index);

$$\begin{aligned}
P_j &= \Pr(d^*_j > 0), \\
&= \Pr(V_j + \varepsilon_j > V_k + \varepsilon_k \text{ for all k} \neq \text{j in K}), \\
&= \Pr(\varepsilon_k < V_j - V_k + \varepsilon_j \ \text{ for all k} \neq \text{j in K}), \\
&= \int_{-\infty}^{+\infty} \left[\int_{-\infty}^{V_j - V_1 + \varepsilon_j} \dots \int_{-\infty}^{V_j - V_k + \varepsilon_j} f(\varepsilon_k) \dots f(\varepsilon_1) \right] f(\varepsilon_j) d\varepsilon_k \dots d\varepsilon_1 d\varepsilon_j \text{for all k} \neq \text{j in K}, \\
&= \int_{-\infty}^{+\infty} (\sum_{k \neq j} F(V_j - V_k + \varepsilon_j) f(\varepsilon_j) d\varepsilon_j \text{for all k} \neq \text{j in K},
\end{aligned} \tag{5}$$

where F(.) is the cumulative density function of ε, f(.) is the probability density function and V is the systematic component of the indirect utility, which is linearly related to $\alpha_j - p_{fj}$, y_f and β. The demand system expressed in this equation is linked to the direct utility function through the $\alpha's$ terms. The quantity demanded provides no useful information due to the absence of the income variable from the optimal choice solution. Thus, it can be represented by a dummy variable taking the value of one if a given fuel is purchased and zero otherwise. The SHHS did not contain price data, notwithstanding that income required to purchase fuel j equals its price; income is included into vector β to gauge the differences in the ability of households to spend on fuels. It should be noted that, inclusion of price with income into the vector β, as in many applications, would exacerbate the extent of endogeneity bias. For example, Hosier and Dowd (1988) used a model similar to equation 5 with price and income added as covariates, however, they reported many enigmatic results. This paper estimates the structural model 5; in addition the standard asset index (see below), which is an *ex ante* measure of wealth, is used to further address endogeneity bias.

Equation 5 accommodates the joint decisions by household on fuel choice and quantity purchased. A close form solution for the fuel's choice equation can be obtained by assuming that the errors in equation 5 follow gumbel distribution and are independently and identically distributed, which leads to the standard multinomial logit (MNL)

$$\mathrm{P_j} = \Pr(\mathrm{x}^*_{\mathrm{fj}} > 0) = \frac{\exp(\gamma'_{\mathrm{j}}\beta)}{\sum_{\mathrm{j=1}}^{\mathrm{K}} \exp(\gamma'_{\mathrm{k}}\beta)}, \; j=1, 2\ldots\ldots K, \tag{6}$$

where γ' is a vector of utility parameters related to β; with the normalization that $\gamma'_1 = 0,$ equation 6 can be expressed as;

$$\mathrm{P_j} = \Pr(\mathrm{x}^*_{\mathrm{fj}} > 0) = \frac{\exp(\gamma'_{\mathrm{j}}\beta)}{1+\sum_{\mathrm{j=2}}^{\mathrm{K}} \exp(\gamma'_{\mathrm{k}}\beta)}, \; j= 2, 3\ldots\ldots\ldots K \tag{7}$$

Equation 7 is interpretable, as the probability that a household with preferences characterized by β, and endowed with income would on average choose x_{fj}. Hence, the factors affecting the "average" choice probability for each fuel can be determined.

However, the γ' coefficients are not readily interpretable, instead the average marginal effects, computed from each observation's marginal effects with respect to an exogenous variable averaged over the entire sample, are used (see Greene 2007). The marginal effect (ME) (δ) of a continuous variable on the probability of adopting the j^{th} fuel for a representative household with characteristics β_h can be established by differentiating equation 7 as,

$$\delta_j = \frac{\partial P_j}{\partial \beta_h} = P_j\left[\gamma_j - \sum_{k=1}^{J} P_k\gamma_k\right] = P_j[\gamma_j - \overline{\gamma}]\text{, j=1, 2.........K,} \tag{8}$$

where P_j is the choice probability and the normalization is ignored. In the case of a binary explanatory variable, say β_{hk}, the (ME) due to change in β_{hk} on the predicted probability of the j^{th} fuel is given by,

$$\delta_{\mathrm{j}} = \Pr(\mathrm{j}=1 | \beta_{\mathrm{hk}} = 1, \overline{\beta}) - \Pr(\mathrm{j}=1 | \beta_{\mathrm{hk}} = 0, \overline{\beta}), \tag{9}$$

with $\overline{\beta}$ denoting the other covariates at their mean value. Since the sub-vector γ' enters every (ME), both through probabilities and the weighted average that appears in δ_j, it follows that both the sign and magnitude of δ_j and γ'_j are not related, (see Greene 2005 for further discussion).

A variety of specification tests in the context of the MNL modelling had been proposed in the literature. Hausman and McFadden (1984)'s specification test is the most common. The test intends to detect departure from the IID errors assumption or the independence of the irrelevant alternative (IIA). The IIA assumption in the context of this paper implies that the household's preference for a given fuel should not change if the fuel set is expanded or an irrelevant subset of fuels is omitted. The IIA hypothesis is often imposed on choice behaviour as a minimum requirement for rationality (see Ray 1973). Cramer and Ridder (1991)'s test for pooling states in the MNL model is also often used to determine if some of the alternatives in the fuel choice set could be aggregated without loss of information. The IIA and pooling tests are used in this paper to guide the selection of the best model that provides the most parsimonious explanation of the data.

4. The Study Variables, Descriptive Statistics, Results and Discussion

4.1 Study variables

The study variables are drawn from the SHHS, which was carried out jointly by the Government of National Unity and the Government of Southern Sudan. The SHHS aimed at a total sample of 25,000 households in the 25 states of Sudan. Finally, 24,553 households are found occupied and 24,046 households were successfully interviewed with 146,723 listed individual members. Overall, the survey contained the most recent and detailed information on key socio-economic and demographic characteristics. The paper drew selectively form these set of variables.

Most of the literature that tested the energy-ladder for the LDCs relied on self-reported current spending or income along with other information drawn from similar surveys. However, current expending and income are not reported in the SHHS; instead, a proxy for permanent income is constructed from the asset index for the households that have chosen a cooking fuel. Although this choice is inflected by the limitation of the SHHS, it is justified in a wide literature. For example, Filmer and Pritchett (1998) argued that, the asset index is not intended to proxy direct income or current spending; rather all are proxies for something unobserved, a household's long run wealth or economic status. Hence, inconsistencies between the asset index and income or current spending cannot be assumed to be 'mistakes' of the asset index as they could just as easily be due to the limitations of income or current spending. Balad et al. (2010) also proposed the use of a measure of wealth based on the asset index to account for possible endogeneity and measurement errors. The asset index, it is argued, is an *ex ante* measure of wealth, which presumably is less subject to endogeneity bias due to the joint allocation of labor supply between self-employment activities and wage earning. It also removes sources of transitory shocks and measurement error in reported self-employed income, especially rural areas dominated by farming and livestock activities, as in the case of Sudan.

The asset index is computed by applying the standard principle component method to available information on 24 assets. These asset indicators relate to the household ownership of consumer durables; the characteristics of the dwelling and landownership; migration and employment status of the head; food security and community assets. Appendix table 1 contains the asset indicators and presents a summary of the components obtained by Promax rotation, which is more suitable for the survey data under study. The weights of the first component are used to obtain a measure for permanent income, assuming that the asset index captures the underlying long-term income through information on the household assets. Since all asset variables are coded 1/0 except the number of rooms and meals these weights are interpretable. For example, from appendix table 2, a household that owns a television has a permanent income higher by

0.788 than one that does not. The household populations are divided into five quintiles ranging from the poorest to the richest according to their rank on the permanent income scale, which furnishes a base for the comparison of the effect of income on fuel preferences for these income groups.

Table 1 provides a summary of the study variables and the way of their construction along with their means and standard deviations. Most of these variables are consistent with the literature on cooking fuel adoption and demand analyses in the LDCs (see Hosier and Dowd 1987 and 1988; Heltberg 2003; Heltberg 2005; Farsi et al. 2007; Mekonnen and Köhlin 2008).

The educational achievement of the household's head is included because it is expected that, education beyond primary level would encourage diversification out of smokier fuels; due both to improved awareness of associated risks and to the relatively higher opportunity cost of fuel collection among the educated. Likewise, dwelling in a relatively modern house, ranking high in the assist index, residing in urban area and owning cooking utensils. The quality of dwelling is identified from data by the type of roofing, it is expected that the dwellers of a house roofed by durable material: metal, cement fibre, concrete, shingle or brick avoid roof strain by adopting cleaner fuels. High ranking in the asset index- i.e. belonging to a relatively richer income quintile versus the poorest reference quintile- is expected to raise concerns about indoor smoke, reduce demand for firewood and encourage switching to available clean substitutes. Thus, this variable provides an indirect test for the energy ladder hypothesis; however, panel data is usually more appropriate for full evaluation of this type of hypothesis.

Residence in an urban area may encourage switching out of wood to clean fuels through enhanced accessibility to modern fuels markets. However, Heltberg (2005) found for Guatemala that, urbanization might not induce switching out of wood. It is shown that many residents in cities depend on, 'purchased wood that is sufficiently costly as to provide a financial incentive for stove adoption or fuel switching', (Heltberg 2005, 4). The extent to which urbanization is an influence in switching to cleaner fuel in Sudan is examined empirically. Another location variable is added to proxy the impact of forest endowment on fuel choice. Households residing in a forest rich state are more likely to adopt biomass fuels, particularly firewood, but forest poor states may be relatively more urbanized and thus the cost of purchased wood could be high to encourage adoption of cleaner fuels; this issue is also examined empirically.

The size of the household is expected to influence fuel choice, but the direction of the effect remains difficult to determine a priori. On the one hand, large household size may augment the availability of labor for wood, straws, residuals and dung collection; and hence, encourage the use of these fuels. On the other hand, large households may use energy more efficiently per member and thus more likely to adopt cleaner and relatively expensive fuel alternatives. The presence of more adult women than average in the household is hypothesized to raise the adoption rate of firewood due to the culture of dokhan, which translates into familiarity with smokier fuels.

Cooking arrangement is also included with the factors that could influence fuel choices in Sudan. The existence of a kitchen is an indicator of the household's standard of living and hence income. It is expected that households having kitchens use cleaner fuels. Similarly, ownership of cooking utensils is expected to trigger fuel switching due to the reduced start-up cost. The impact of cooking outdoors is generally less obvious, however, in the context of Sudan, it may imply the use of simple techniques for cooking in open fire, and therefore may encourage the adoption of smokier fuels relative to cooking indoors.

A dummy for gender is added to discern the extent to which female-headed households could access clean fuels. The age of the household is included to proxy the extent of habit persistence; older heads compared to younger ones may be less inclined to use modern fuels as a matter of habit. The number of meals served per day is added as an indicator of the household's economic status. Generally, serving more meals than average implies that the household is relatively wealthier. However, there is no information on the type of food in the SHHS. It may be the case that, the meals offered are dominated by Sudan's staple food, Kesra or Aseda, which are typically baked on a flat thin plate or a pot made of iron or burnt clay usually heated on four or three stones firewood stove. This implies that, serving more meals would induce firewood adoption.

The next section provides the graphical analysis of the unconditional correlation between the intensity of fuel use and selected households' characteristics. It also reviews the indicators to the risks of indoor pollution.

4.2. Descriptive analysis

The energy question of the SHHS contained twelve options on the primary cooking fuel used by the household during the last two weeks before the survey. These were; electricity, liquid propane gas, natural gas, biogas, kerosene, cool lignite, charcoal, wood, Straw/shrubs/grass (henceforth straws), animal dung, agricultural crop residuals and other(s).

An initial inspection of the responses to these options revealed that, liquid propane gas and natural gas could be aggregated into LPG as the latter variable contains less information to merit investigation as a separate option. The same applies to cool lignite and charcoal, which are aggregated into charcoal. Appendix table 2 presents a summary of the reported use of primary cooking fuel countrywide. A number of observations follow from this table. Firstly, solid fuels- which include wood, charcoal, crop residuals, straws, dung- are the primary source of cooking energy in Sudan accounting for 72.4 % of the responses. This figure is only marginally less than the 74 % reported in the Forest National Corporation demand study, (see FNC/FAO 1995), and reveals a mere 1.6 % decline in the use rate of solid fuel over more than a decade. For all the respondents, firewood contributed by 53.7% to total household energy use, followed by charcoal, which contributed by 15.6%. The patterns of firewood usage vary from 98.6% for the less urbanized and forest rich states, like West Equtoria, to 3.5% for the relatively urbanized Khartoum state. In contrast, charcoal use is concentrated in the more urbanized states, with Sinnar and Gadarif showing high rate of use, about 37% each. Both states are adjacent to the big charcoal production zones in Sudan. Similar patterns of firewood and charcoal uses were found in the literature surveyed in Aronld et al. (2003).

Secondly, the use of non-biomass and relatively clean cooking fuels namely LPG, biogas, kerosene and electricity; combined accounted for only 6.7% of cooking energy consumption in Sudan. The patterns of demand for these fuels remain highly concentrated in the three states of Khartoum, Warap and Sinnar, which jointly consumed about 50% of these fuels.

Finally, the option of "other(s)" generated relatively large responses representing 19.7% of the total. Since the list of fuel options in the survey questionnaire is rather exhaustive, it seems that the responses to category of "other(s)" represents situations of fuel stacking where the respondent was unable to decide on a primary fuel. This appear plausible, because the responses to this option concentrated in three states, Khartoum, Gezera and River Nile, which are more urbanized with a relatively developed markets for diversified cooking fuels. Notwithstanding, this option is dropped along with the categories with missing information leaving 19,716 households with complete records for the subsequent analysis.

Appendix table 2 clearly indicates that, biomass is the main source of cooking fuel despite the pursuance of policies encouraging switching to LPG as enshrined in SFNC (2003). From the outset, this implies that, the existing switching policies need to acknowledge the continued dependence on biomass as well as the possibility of existence of considerable fuel stacking. Thus, other complementing policy is needed in order to improve the efficiency of utilization of dominant fuel sources.

Figures 1 to 3 picture the extent to which the patterns of usages of LPG, charcoal and firewood correlate with households' living standards and location. Figure 1 plots the percentage of the households adopting a given fuel against the permanent income quintiles. As appears, the figure corroborates the earlier observation that both wood and charcoal are the leading cooking fuels in Sudan.

Although the use rate of firewood declines as income increases, it remains relatively high for the rich, averaging about 67% for all income quintiles, and about 44% among the richest income quintile. In addition, both charcoal and LPG steadily increase with the level of income for all income quintiles averaging respectively about 20% and 7%, however, none of these fuels overtakes firewood even for the rich quintile.

The patterns of urban and rural fuel usages; depicted in figures 2 and 3; show notable differences. The average adoption rates of charcoal, wood and LPG in urban locations are 41.4, 39.3 and 15.1 percents respectively, while the corresponding rates for rural users are 12.1, 78.0 and 4.7 percents. The response of firewood to income growth is less uniform for urban users compared to rural users. As seen in figure 2, wood use peaks as the dominant fuel for the middle-income quintile and sharply declines afterwards. Charcoal tends to uptake firewood starting at income level beyond the middle-income quintile and dominates urban fuel usages thereafter.

The abundance of wood sources in Sudan and the relatively low collection cost seem to explain the dominance of firewood. Charcoal is the leading fuel among urban dwellers particularly for the high-income quintiles. The uptake of LPG is rather limited for all cooking fuel users suggesting that policies for fuel switching also need to address factors relating to the aggregate supply side of the LPG in addition to the on-going end user-price subsidy.

The use rate of LPG is notably high as from the second income quintile, however, it uptakes firewood for richest income group. Figure 3 shows that, the usage of firewood is declining with income growth, yet wood remains the main cooking energy source for the rural population. No fuel clearly displaces the other for the various income groups implying that fuel switching is likely to be less responsive to income among rural dwellers.

Figures 4 and 5, respectively, picture the patterns of adoption of electricity; biogas; kerosene; straws; crop residuals and dung in urban and rural locations. These fuels are depicted as "marginal fuels" because their combined use rate averaged 5% at the national level. However, the adoption rate of the given individual fuel varies by location and income group. The urban and rural poor use straws followed by crop residuals and dung more frequently. The other fuels are relatively used more by higher income quintiles with a declining frequency except for dung and residuals for the urban richest group. Electricity is less frequently adopted as fuel especially among the rural dwellers. Switching out of crop residual among urban households and out of straws among rural households seems more responsive to income growth compared to the other marginal fuels.

The adoption of biomass for home use is as old as mankind, but overtime it became a source of heath concern, due to the increasing awareness about its risks especially indoor pollution. More recently, the World Health Organization report (2002) indicated that indoor air pollution is responsible for 2.7% of the global burden of disease. The IEA in 2007 estimated that 1.6 million women and children die annually from exposure to indoor pollution.

The contingency tables analysis is utilized to gauge the extent of the risks of indoor pollution for both the users and non-users of smokier fuels by predominant cooking habitats. This is followed by the cross-tabulation analysis of the children reported for suspected pneumonia among users and non-users of smokier fuels by cooking habitats and income; the results are shown, respectively, in Tables 2 and 3. The $\chi 2$ statistics and the corresponding p-values (not reported) indicate that, the association between the row and column variables shown in these tables is not due to chance.

As seen in table 2, about two-thirds of the population countrywide uses smokier fuels for cooking and more than 17% live in households that cook in all-purpose room. The level of risk associated with exposure to emissions of carbons and other particulate matter is very high for this group. Also 27.6% of the households who cook in a separate room are exposed to these risks depending on the duration of cooking, the quality of ventilation and the number of the attending household members. Generally, women do most of cooking in Sudan as a matter of culture; hence, they are more likely to inhale more smoke than men. Children tend to be indoors with their mothers and are more likely to develop diseases resulting from a given level of exposure, especially among lower income quintiles.

The table also shows that, the patterns of usage of smokier fuels and cooking arrangement vary considerably by household location. The proportion of rural households adopting smokier fuels is very high compared to their urban counterparts, 79.3%, versus 36.7 %. Cooking in kitchens and outdoors is more frequent among rural households than urban ones; the combined percentages are 61.9 and 27.9 respectively. This may partly compensate for risks of exposure. However, the proportion of those who cook in all-purpose room remains very high in rural areas compared to urban ones, 17.4% versus 8.8%. Similar patterns of use of smokier fuels by cooking arrangement for urban and rural dwellers are found in other comparator countries. See for example, Heltberg (2005) for Guatemala, Heltberg (2003) for a group of developing countries and Jack (2004) for Peru.

The SHHS collected information about children suspected of having pneumonia (acute respiratory infection) during the last two weeks before the survey. Countrywide the prevalence rate of suspected pneumonia is 12% among children below five years of age who accounted for about six million of the total population. Table 3 presents the summary of the contingency analysis between observed child cases by cooking habitat and location of the households. As seen, more child cases are reported among users of smokier fuels in comparison to non-users, 69.9% versus 30.1%. The χ^2 test (not reported) confirmed that, the association of child cases with smokier fuels is systematic.

Children who live in urban appear to suffer most from exposure to smokier fuels. The reported child cases among users of smokier fuels in rural and urban areas are respectively 76.9% and 53.1%, whereas the corresponding ratios for non-users are 30.1% and 46.9%. Moreover, suspected pneumonia is more frequent among children belonging to households cooking indoors. Countrywide, the all-purpose room and designated kitchen combined reported 43.4% cases versus 26.5% for similar users cooking outdoors. The corresponding ratios among non-users are 21% and 9.5% respectively. Heltbergy (2005) found comparable results for Guatemala.

The results of the contingency analysis of child cases by income quintiles, based on the asset index, are shown in table 4. The total number of infected children appears to correlate marginally with the economic status of the household, as it declined by only 1.6% for the richest compared to the poorest income quintile, with a spike in the middle. A similar result is noted in the SHHSR's (2007) report, despite the differences in the assist set used for the construction of the assist index and the sampled households. The SHHSR report also noted that, under-reporting of child cases tends to be higher among the poorest households. The percentage of mother/caretaker awareness of the danger signs of pneumonia is found to be higher among mothers in rich households (22.1%) than those belonging to poor homes (15.2%).

Notwithstanding, there was significant negative correlation between child infection and the economic status when the suspected child cases are tabulated by income quintiles and cooking arrangement. As seen in the table, the percentage of reported child cases drops from 82.4%, among the poorest quintile to 56.4% for similar users among the richest. In addition, 41.4% of the child cases belong to the poorest income groups cooking in all-purpose room whereas the corresponding figure for the richest is 0.1%. The χ^2 test for associating child pneumonia cases with the adoption of smokier fuels by the respective income quintiles across cooking arrangement; is highly significant for all groups at less than 1% significance level. This implies the existence of positive correlation between the incidence of child infection and the patterns of adoption of smokier fuels by cooking arrangement and by income group shown in the table. However, it should be noted, while χ^2 test from the contingency analysis can determine the existence of relationship between variables, it remains silent on its strength.

The preceding descriptive review of the unconditional correlations reveals considerable variations in the patterns of fuels uses by fuel type as well as by the socioeconomic status and location of the household. This motivates further analysis of the effects of these factors on the households' choice probabilities for cooking fuels. The next section presents the results from this analysis and indicates the associated environmental risks.

4.3 MNL results and discussion

The MNL model implied by equation 7 is estimated with eight fuel options: LPG, biogas, kerosene, charcoal, firewood, straws, dung and crop residuals. The dependent variable is the given fuel choice and LPG is the reference category. As seen in Figures 4 and 5, electricity contains fewer observations, and the estimated binomial logit equation for electricity to initialize the (MNL) failed to converge. Thus, it is aggregated with LPG as both belong to the group of modern cleaner fuels (henceforth referred to as LPG); the results of the estimation are shown in appendix table 3. However, before discussing these results, it is important to test for the robustness of the estimated model.

Initially, all the predictors in the model are tested for multicollinearity, because the presence of collinearity might increase the variances of the estimated coefficients, making them unstable and uninterpretable. However, there is no standard testing procedure to follow. Since the model's functional form is less relevant for this testing, the multicollinearity diagnostic statistics from the ordinary least squares estimation are used, (see Menrad1995). The variance inflation factors VIFs (not reported); which show how the estimated coefficients are inflated due to collinearity, reveal no problem. All of the calculated VIFs were below 2 except for income and cooking arrangements, which are entered as multiple step dummies. Even for these predictors the highest VIF is 3.9 for the richest income group. In addition, the coefficients correlations revealed no problem; the highest correlation coefficient is 0.749[2]; also, the condition indices (CIs), which are the square roots of the ratios of the highest eigenvalue to each successive eigenvalue, are all below 30 except one.

Although these statistics imply that, vector β_{hj} is not collinear; it should be noted that, the acceptable threshold values for the VIFs, the coefficients correlations and the CIs are arbitrary, and widely vary in the literature, (see O'Brien, 2007 for further discussion). Thus, the overall fit of the model versus the statistical significance of the individual coefficients is also used. High model significance without corresponding high significant coefficients of the predictors can be due collinearity, (see e.g. Ajmani 2009). As shown below these diagnostic statistics also reveal no serious collinearity.

In addition, the results of testing for IIA violation using Hausman-McFadden specification test are reported in Appendix table 4. As seen, some test statistics are negative; however, the authors noted that, 'we have occasionally found the test statistic to be negative', and concluded that, this is strong evidence against rejecting the null hypothesis, (Hausman and McFadden, 1984: p. 1226 footnote 4). Overall, two tests reject the null hypothesis implying that, the assumption of zero error covariance is violated and that the choice set may contain closer substitutes.

In many applications IIA assumption is found too restrictive; and much of the literature on discrete-continuous choice modeling concerns with alleviating this assumption, (see Greene 2005; Kennedy 2003 for discussion). However, all the alternative modeling strategies have assumptions of their own, which are difficult to meet with data available for this paper. Another strand of literature questioned the power of IIA tests. For example, Long and Freese (2001) indicate that, the results of the Hausman and Small-Hsiao IIA tests may provide little guidance to violation of the IIA condition. Even in a well-specified model, IIA tests often reject the assumption when the alternatives seem distinct, (see also Cheng and Long 2007). Perhaps the best way to proceed is to follow McFadden's advise that, the IIA implies that the MNL model should be used in cases where the alternatives can be 'plausibly assumed to be distinct and weighed independently in the eyes of the decision-maker', (McFadden 1973: 113). However, as noted by Long and Freese (2001), identifying a model with distinct outcomes that are not substitutes seems reasonable; however, the advice is unfortunately ambiguous. May be the ambiguity relates to the question of identifying the distinct outcomes on a priori basis. Furthermore, in some cases, researchers may be interested in examining the impact of introducing a new alternative, which often affects close substitutes.

Notwithstanding, the results of the IIA tests are taken in this application to imply that, the alternatives in the choice set K are not mutually exclusive violating the model assumption. Cramer and Ridders' pooling test is used to identify the alternatives that could be further

[2] A high correlation coefficient would be about 0.8 or 0.9 in absolute value (Kennedy 2003,209, see also Judge et al. 1985), however, while the test detects pairwise collinearity it may not detect collinearity for three or more variables.

aggregated to establish a parsimonious and statistically consistent model. The results of the pooling test are reported in appendix table 5. The tests reject pooling of alternatives in the model. Clearly, compromises are inevitable for achieving model parsimony. Some of the marginal fuels could be merged in view of their very low share in total fuel-portfolio and their relatively small χ^2 scores in the pooling tests. Accordingly, a five options model is formulated by further merging biogas and kerosene with LPG and merging dung and crop residuals together. These new categories are referred to, henceforth respectively, as LPG and dung/crop residuals.

The results of estimating the five options model (II) are shown in appendix table 6. The IIA and pooling tests reveal that model (II) is reasonably specified, (see appendix Tables 7 and 8). The IIA tests confirmed that the underlying utility function is correctly specified and it captures all sources of correlation explicitly and the unobserved part of utility is a 'white noise'. However, even for reasonably specified models, it is recommended to correct for possible unobserved heterogeneity due to clusterin*g* of respondents. All the reported asymptotic standard errors are cluster-corrected by state to account for potential dependence of errors within state, (see e.g. Greene 2007). To further gauge the robustness of the results, the model is estimated without the extrapolated income variables; none of significantly estimated coefficients turns less significant implying that adding these controls does not drive the results.

The overall fit of model (II) in terms of the adjusted McFadden pseudo R-squared is almost identical to the general model (I). R-squared in the respective models is 0.3014 and 0.3016 implying that about 30% of the log-likelihood is explained by the given model. It should be noted that;' low R^2 is typically observed in cross-sectional data with a large number of observations', Gujarati 2004: 544). However, the value of χ^2 statistic, which tests the null hypothesis that all the parameters of the given model have no effect, is highly significant implying that R^2 is statistically significant and the given model is well specified. In addition, more than 72% of the estimated coefficients of model (II) are statistically significant compared to 65% in the general model. This finding, in connection to the significant χ^2 statistic and R^2, which supports the overall model fit, provides further evidence against collinearity and that model (II) is more efficiently estimated. The following discussion focuses on the second model and only marginally refers to the general model as far as relevant.

Table 5 presents the average marginal effects AMEs for both models. However, the computation of the associated asymptotic standard errors is difficult; hence, the standard errors of the marginal effects MEs are used instead, (see Greene 2007). The statistically significant coefficients are bolded; Appendix table 9 shows the estimated MEs and their standard errors.

Most of the estimated effects of the factors included in the analysis are statistically significant and broadly in line with prior expectations. More specifically, model (II) indicates that, the level of education of the household's head significantly affects the probabilities of fuel adoption predicted by the preferred model. Observing a household's head with primary education, relative to the base category, (uncompleted primary or non-educated heads), would on average increases the probability of adopting LPG and charcoal, respectively, by 0.06% and by 0.14%. This effect is also estimated to significantly decrease the choice probabilities of firewood, straws and residuals, respectively, by 0.19%, 0.004% and 0.01%. Post-primary education relative to primary and below involves even higher adoption probabilities of LPG and charcoal, while it reduces the likelihood for firewood, straws and residuals.

Since education is a crucial component of human capital and expected to positively correlate with income, both the pattern and magnitude of the predicted fuel choice probabilities at various education levels appear to lend support to the energy-ladder hypothesis. That is, as the level of education of the decision-maker in the household increases, the household generally moves up the energy ladder from smokier fuels towards cleaner options; this result is also confirmed by model (I).

The demographic variables of the household are also important determinants of the choice of fuel sources, however their statistical significance varies. Firstly, a one percent increase in the size of the household tends to increase on average the probability of choosing firewood, straws and dung/crop residuals by 0.009%, 0.02% and 0.007% respectively. The same effect is estimated to significantly reduce the probability of adopting LPG and charcoal by 0.03% and 0.006%, respectively. Secondly, the AME of the age of the households' heads reveals that, LPG and charcoal are more likely to be adopted by younger heads, whereas older heads tend to choose firewood and straws. However, age does not seem to be associated with the likelihood of choosing dung/crop residuals options; the estimated AME is not statistically significant. Moses and Fraser (2003) reported similar effects for age in the case of Kisumu district in rural Kenya. Finally, female headship of household, or a relatively high ratio of adult females therein, is closely associated with asset poverty and both tend to raise the likelihood of choosing the smokier fuels of straws and dung/crop residuals. Specifically, the effect of female headship relative to that of males' significantly increases the probability of adopting straws and dung/crop residuals crop residuals by 0.01% for each fuel, whereas the estimated effects are negative for the other fuels, but insignificant. In addition, a one percent rise in the ratio of adult female in the household significantly reduces the probability of choosing LPG and charcoal, respectively, by 0.07% and 0.002% and increases the probability of adopting firewood by 0.08%. However, this effect is negative in the case of straws and positive for dung/crop residuals, but insignificant.

The statistically significant effects of female headship and the number of adult women in the household on the adoption probability of the smokier fuels indirectly confirm the hypothesis that, the culture of dokhan develops loyalty for smoker fuels in Sudan. It is also likely that, an increase in the number of women in the household reduces the opportunity cost of biomass fuel collection from the open forests and commons.

The characteristics of the house itself matter for cooking fuel adoption strategy. The estimate indicates that, the effect of modern roof significantly increases the probability of choosing LPG and charcoal, respectively, by 0.08% and 0.002%, and reduces the probability of adopting firewood by 0.08%. The same effect is predicted to be negative for straws and dung/crop residuals, but statistically insignificant, except for crop residuals in the general model. Likewise, observing a household equipped with cooking utensil relative to one without, raises the adoption probability of LPG and charcoal by 0.02% and 0.01%, respectively, and reduces the choice probabilities of firewood, straws and dung/crop residuals by 0.01%, 0.02% and 0.01% respectively. All these effects are significantly estimated at less than one percent implying that the start up costs is critical for adopting modern fuels. In addition, the effect of existence of a kitchen, relative to the base category, is predicted to raise the probability of adopting LPG by 0.02% and reduces the probability of using straws and dung/crop residuals respectively by 0.03% and 0.01% except for crop residuals in the model (I), where it is negative but insignificant. Although the effect of the existence of a kitchen is not significant for firewood and charcoal, the positively estimated AMEs for these options imply that, the availability of kitchens provide storage space for these bulkier fuels and hence encourage their use. Similar result is found in urban Ouagadougou (see Ouedraogo 2006).

The estimated effects for cooking outdoors, relative to the base categories, tend, on average, to reduce the probabilities of choosing LPG and charcoal, respectively, by 0.02% and 0.01% and raise the choice probabilities of firewood and dung/crop residuals by 0.02%. This may be due to the fact that, cooking outdoors is problematic during rainy and stormy days. In addition, the frequency of cooking per day is estimated to have a significant effect in the case of firewood and charcoal. For example, a 1 percent increase in the frequency of servicing meals is predicted to increase the adoption probability of wood by 0.04% and reduces that of charcoal by 0.07%. The predicted significant negative choice probability for charcoal suggests that an increase in the frequency of meals may induce economies of scale in cooking for charcoal users and hence reduce the frequency of cooking per meal.

The location of the household is estimated to be an important factor in the decision of adopting primary cooking fuel. In particular, observing a household in a better wood-endowed location relative to the less wood-endowed raises the adoption probability of firewood by about 0.2%, whereas, this effect reduces the adoption probabilities of LPG, charcoal, straws and dung/crop residuals by 0.11%, 0.07%, 0.01% and 0.005% respectively. Likewise, residence in an urban site relative to rural location tends to increase the probabilities of using LPG and charcoal, by 0.03% and 0.17%, respectively, and reduces the likelihood for wood and straws by 0.19% and 0.01%. However, this effect is not statistically significant for dung/crop residuals, whether estimated jointly or separately as in model (I).

The structural model does not permit fuel trade-up as household's income rises. More important, it is difficult to fully evaluate the energy ladder type of hypothesis with cross-sectional data, because the hypothesis also implies change overtime. However, income is broken into stepwise dummies, corresponding to five income groups, to approximate the effect of this change (see also Hosier and Dowds’ 1987 seminal work). The estimated significant effects suggest that, moving-up the income scale relative to the lowest base scale raises the adoption probabilities of LPG and charcoal and discourages the use of firewood and the other smokier fuels. More specifically, the estimated AMEs for the various income quintiles beyond the poorest are uniformly significant and positive for charcoal and negative for firewood, implying that households belonging to these income quintiles adopt charcoal and diversify away from firewood.

Moreover, the middle and richest income quintiles relative to the poorest opt for LPG, the estimated AMEs for these quintiles are, respectively, 0.01% and 0.02%, whereas the other effects are not significant. These results qualify the wood-puzzle implied by the visual impression of Figures. However, the response of straws and dung/crop residuals to income appears broadly insignificant except for the richest users of the latter. This finding is at odds with the energy-ladder hypothesis, which is broadly corroborated by the other results. As revealed by model (I), the response of crop residuals is significantly negative for the second income group relative to the base and positive for the richest, while the response of dung is insignificant for all income quintiles. A possible explanation for the perverse result associating the use of crop residuals with the richest may be that, crop residuals are collected from own farm, where their supply and use increase with the level of the household wealth in terms of landholding.

Generally, the intercepts of the fuel demand equations implied by the structural model are expected to be positive and are interpretable as marginal utilities in absence of the effect.

However, the intercepts of the estimated logit fuel choice equations can be interpreted in many ways. As the case in regression models in general, these intercepts enter the calculation of the predicted probabilities of each outcome for a household with given characteristics. They could be used to predict the expected probability of an outcome all other things remaining equal and they could also be used as indicators of model misspecification. Nevertheless, since the estimated model reasonably passes the regular diagnostic tests, it is intuitive to interpret the intercepts as average utilities when the independent predictors equal zero. As revealed by the preferred model, the intercepts for LPG and firewood are both positive and statistically significant, while the other intercepts are negative. The relatively large and positive intercept for firewood suggests the existence of substantial inertia for this fuel; may be due to the relatively easy accessibility for wood, the simplicity of cooking techniques and the loyalty for wood due to the entrenched habit of dokhan. The significant intercept of LPG seems to bear the effect of the ongoing subsidization of modern fuels, including LPG, which aims to encourage a switch out of biomass. The negative and significant intercepts for straws and dung/crop residuals seems to denote substantial disutility from choosing these fuels, whereas the intercept for charcoal is not different from zero.

The overall result of the analysis indicates that, the adoption of modern fuels LPG, electricity, kerosene and biogas, is significantly related to the standard of living of the household. That is households with the following characteristics: relatively rich with formally educated heads; having fewer members, particularly females; residing in a modern dwelling equipped with kitchen and cooking utensils; and located in urban areas, tend on average to adopt modern fuels.

These covariates also predicted charcoal as an important intermediate fuel in urban areas, especially that, relocation of a household from a rural to an urban area is shown to raise charcoal adoption probability by 0.17% and reduces firewood choice by 0.19%. This suggests that, urban growth would further push charcoal industry towards the rural hinterland with obvious effects on de-greening the economy as well as on cost of fuels given the current mode of charcoal production. At present, charcoal is hauled over more than 1000 Km to the cities in central Sudan from Southern Kordofan and the riverine forests in the Blue Nile and Upper Nile states, (see UNEP 2007). In time, the distance between production and consumption points will continue to increase due to the large-scale felling of wood for commercial extraction of charcoal.

Firewood is found to be a universal cooking fuel in Sudan, especially among asset poor households, residing in forest rich locations, with more members and higher ratio of women and relatively less educated heads. Households with these traits account for more than half of firewood users. It is also found that, 79.3% of the rural households adopt smokier biomass. These results are in line with the empirical literature on poverty-environmental hypothesis, which upholds that, poor households depend more on environmental resources than the rich. Hence, the results suggest that, policies geared towards poverty reduction are necessary for environmental sustainability. More important, conservation policies based on restriction of access to the common biomass resources would lead to high private losses, increased inequality and more poverty. In this regard, the high private benefits due to collection of biomass from the common versus the social costs of deforestation imply that a uniform tax on smokier fuels would also result in a lose-win situation. Notwithstanding, a regulatory tax on large-scale commercial production of charcoal could be more effectively administered for forest sustainability and green economy.

5. Policy Implications and Conclusions

5.1 Policy implications

The results highlighted a number of factors relevant for public policy-making in the households' energy sector in Sudan. Generally, a multifaceted approach to policy-making combining enhanced biomass production and efficient utilization with reduced health risk is needed to complement the existing switch policy (focusing on subsidies), which is also consistent with the MDGs aiming to halve biomass users by 2015.

The findings confirmed that, income growth and urbanization induce switching out of wood towards charcoal. This process over time implies that, harvesting of biomass for charcoal at very significant conversion losses in addition to the other uses of forests would seriously burden the already fragile environment in Sudan. Of course, increasing the feedstock is an obvious policy response to enhance biomass production. While afforestation and reforestation policies exist, the main challenge is that the implementation capacity is weak. However, one prospect is to empower the institutions mandated with forest laws and the other is to expedite the implementation of the national program on Reducing Emissions from Deforestation and Forest Degradation (REDD) benefiting from the recently established REDD desk in the country. In addition, there is great potential for a policy geared towards improving the efficiency of biomass resource use. The traditional way of charcoal production could be replaced by modern charcoal kilns, which are more efficient in terms of the wood required as well as the amount of charcoal wasted in the production process. Also improving wood harvesting methods could reduce the pressure on forests. Moreover, the development of non-biomass energy sources for cooking could relieve the growing pressures on forests. Currently there is limited utilization of solar cookers in prisons and displaced population camps. The abundantly available solar sources in Sudan provide wide chance for use of solar energy for cooking.

Despite the existence of substantial inertia for wood, the analysis-in line with the energy ladder-broadly confirms that income is an important factor determining households' transition to clean energy. Hence, income subsidization and income growth inducing polices are likely to influence fuel switching. In addition, a policy that raises the level of education beyond primary is predicted to significantly increase the probability of adopting cleaner fuels and reduce the likelihood for biomass, particularly wood. Likewise, an extended electrification program can provide important catalyst for the transition to modern fuels, especially in view of the extremely low electrification in Sudan even by comparators standards. Improving LPG distribution networks not only encourages diversification away from biomass, but also enhances entrepreneurships in cylinders distribution, refilling and maintenance.

A significant negative correlation of health risks, as indicated by the incidence of child infection, with permanent income was found. Hence, economic development and income growth are expected to mitigate these health hazards; also, fuel switch policies could provide medium to long-run solution. However, the high health risks among the poorest income quintiles warrant a household subsidy for modern fuels and for fuels' capital cost as short-run solution; especially that, the start up costs is found critical for adopting modern fuels for these income groups. A uniform Pigovian tax on smokier fuels might not be equitable as both the poor and the relatively rich are found to consume them. Instead, taxing selected forest products, e.g. roundwood for charcoal production and scented wood, could be administered to regulate biomass consumption and provide for forest sustainability.

5.2 Conclusions

This paper drew from SHHS (2006) in order to explore the patterns of cooking fuels uses by type, economic status and location of households. It also described how these patterns of fuels usages reflect concerns about risks of indoor pollution and deforestation. In addition, a discrete choice model consistent with consumer theory is applied to establish the factors that determine the household fuel-choice decisions in Sudan. The preferred model passed the standard diagnostic testing and provided parsimonious representation of fuel choice probabilities, but it should be noted that, this is achieved at the cost of suppressing details on closer substitutes in the fuels set, which may contain important information relevant for policy design. It is also assumed that, all fuel options included in choice set are accessed through 'out of pocket' spending; however, it is difficult to verify this assumption from the data. These caveats need to be considered in interpreting the findings and their policy implications.

The descriptive analysis showed that, firewood and charcoal are universal cooking fuels in Sudan and are likely to dominate the fuel-portfolio even in the long run. Although the use rate of firewood declines as income increases, it remains relatively high for the rich; and averages about 67% for all income quintiles and about 44% among the richest. There is no simple explanation for this; it may be due to the preference for the taste imbibed by firewood to the food and the predilection for using certain traditional cooking techniques or due to the culture of *dokhan*. Firewood also largely dominates the rural cooking energy-portfolio followed by straws, LPG, kerosene, biogas and electricity. The urban fuel-portfolio is found to be dominated by charcoal, as primary fuel, followed by LPG with limited use of biogas, kerosene and electricity. Urban and rural poor use straws followed by crop residuals and dung more frequently. The combined use rate of fuels other than biomass and LPG averaged 5% at the national level.

Two third of the population countrywide are found to use smokier fuels, namely firewood, straws, dung and crop residuals. More than 17% of the population lives in households that cook with smokier fuels in an all-purpose room. The proportion of users to non-users of these fuels is very high among rural dwellers compared to urban counterparts, 79.3%, versus 36.7%. It is known that the risks of exposure to smokier fuels are very high among women and children under five years of age who usually remain indoors with their mothers. The reported child cases are found to be more than double among users of smokier fuels compared to non-users. Rural children appear to suffer most, accounting for 76.9% of the cases among users of smokier fuels compared to 53.1% for urban users. The corresponding ratios for non-users are 30.1% and 46.9% respectively. In addition, pneumonia is more frequently associated with the adoption of smokier fuels especially among users cooking in a all-purpose room and in a kitchen, as an intermediate stage, which combined reported 43.4% of the child cases versus 26.5% reported by similar users cooking outdoors. The corresponding ratios among non-users are 21% and 9.5% respectively. Children belonging to the poorest households cooking in all-purpose room are exposed most to the risks of indoor pollution, with 41.4% reported cases versus 0.1% for the richest with a similar cooking arrangement. Although the degree of health hazard is assessed through the contingency tables, further measures of association with rich data need to be considered.

The socioeconomic characteristics of the households are estimated to be important factors influencing the probabilities of fuels adoption. The results of the discrete choice analysis confirmed that, households are moving-up the energy ladder and their fuel choices are determined by their level of permanent income proxied by the asset index. In addition the formal education of the households' heads, as well as the residence in modern dwelling equipped with kitchen and cooking utensils tend to encourage adoption of modern fuels. Large size households with a higher share of women as well as the female-headed households and residence in forest-rich areas significantly induce firewood use including other smokier fuels.

While it is difficult to control for fuel prices and labor costs from the data, the results suggest that, there were considerable correlation between large size households; with high share of women; and the probability of adoption of smokier fuels, including firewood. This implies that, the demand and supply of these fuels could be broadly non-separable and their markets are relatively thin and concentrated compared to those of LPG and charcoal, which seem more commercialized. Notwithstanding, the reform of these markets, especially firewood market, could benefit a large number of the poor who appear as important buyers and sellers of wood.

Charcoal is found to be the primary fuel for the relatively rich and for the urbanized; hence, both income growth and urbanization seem to induce switching out of wood towards charcoal. This trend, over time, would increase the distance between charcoal production and consumption points as the nearby stock of forests continue to be depleted with the obvious implications for cost of fuel and the de-greening of the economy. Policies aiming at reducing the rate of deforestation need to focus on changing the behavior of the large-scale charcoal harvesters.

In spite of the fact that the lighting source is not clearly indicated in the data, the use of electricity as cooking fuel is found to be extremely limited. The UNEP (2007) noted that, the Sudanese cities are unusual even by LDCs standards in that," the level of electrification is overall extremely low, and that the majority of the urban population still relies on wood for energy", (UNEP 2007,133). Recent literature indicated that, the availability of electricity is an access proxy for fuel market development and it acts as catalyst for people to switch from traditional to modern fuels, (see Barnes et al. 2004). The extent to which a household substitute or complement fuel uses is difficult to ascertain from the present data, however, fuel stacking could be very common and is an issue that requires further investigation.

Although the MNL modeling provided parsimonious representation of fuel choice probabilities for Sudan, the results are by no means final and could be improved in many ways. Firstly, the constant marginal utility associated with the MNL choice and demand functions does not allow for fuel trade-up as the expenditure on fuels increases. Yet, the model is widely used to test, e.g. the energy-ladder hypothesis following the contribution of Hosier and Dowd (1987,1988); this paper is not exempt from this pitfall. It would be interesting to extend the model to allow both for flexible specification of affordability, by including fuel collection time beside income, and for fuel trade-up to reflect the possibility for fuel superiority. Secondly, the extent of fuel stacking needs to be further explored, especially that the results confirm the existence of strong inertia for wood due to cultural factors, which affects fuel switching policies. Thirdly, even though the paper controls for unknown heterogeneity, further analysis explicitly accounting for random taste variations beyond those linked to the observed households' characteristics would enrich the results. Finally, the health indicator used to proxy the degree of biomass hazard is self-reported, and hence may tend to under estimate the extent of health risks, more refined measures of indoor pollution are inevitable for the evaluation of the health impact of smokier fuels.

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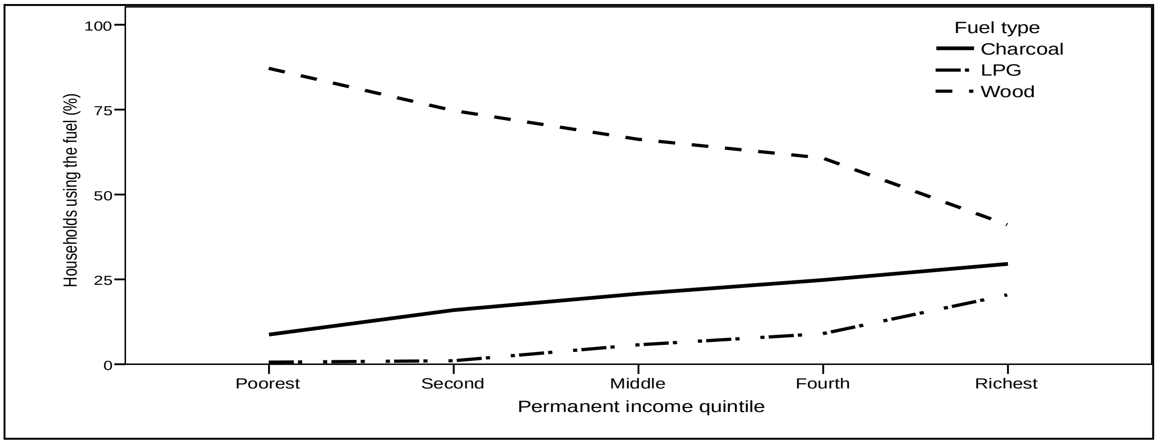
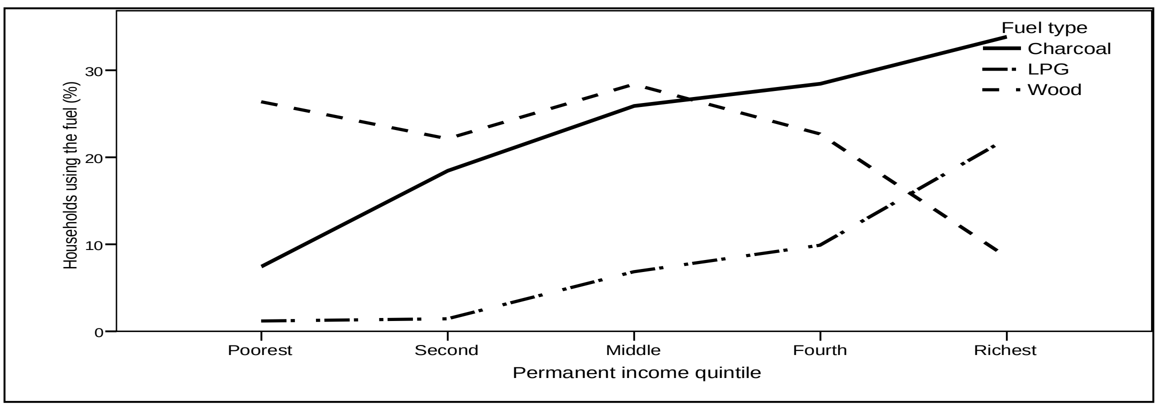
Figure 1: National Usage of LPG, Charcoal and Firewood for Cooking



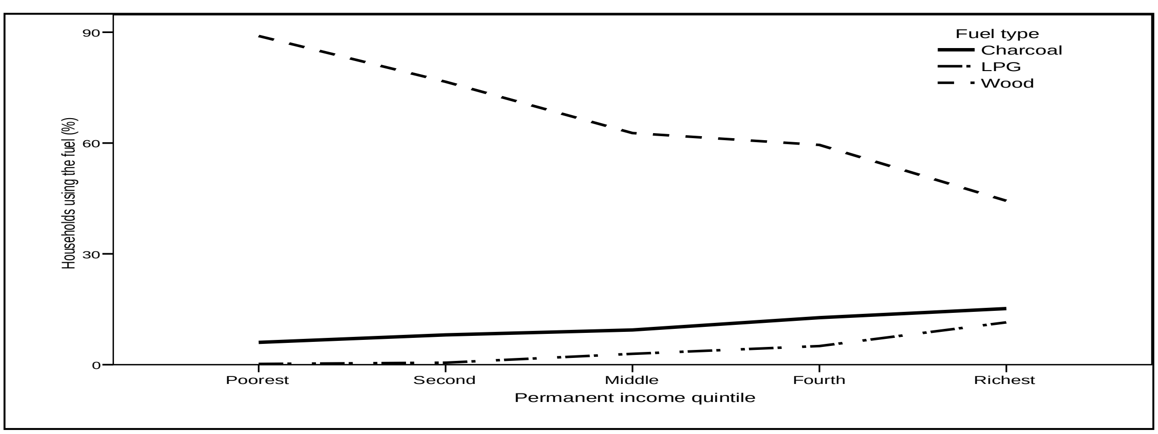
Source: Plot based on SHHS (2006).

Figure 2: Urban usage of LPG, Charcoal and Firewood for Cooking



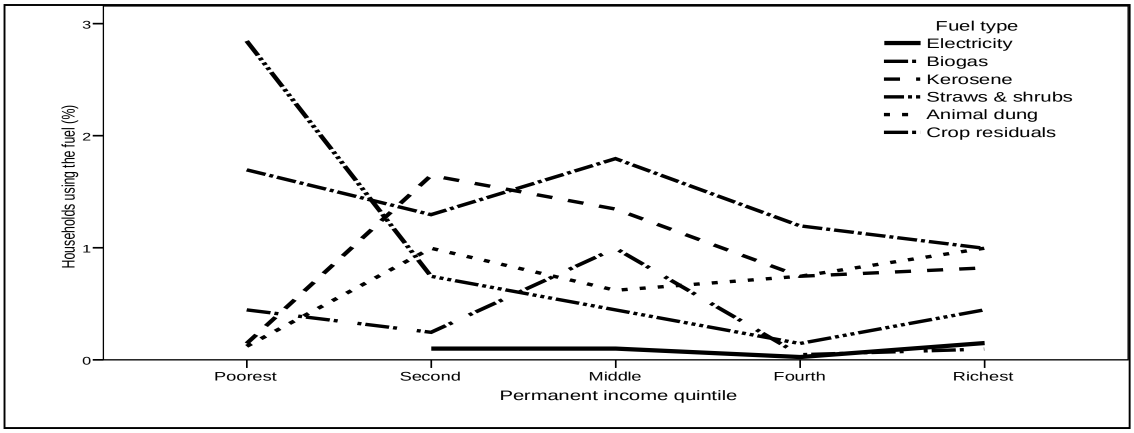
Source: Plot based on SHHS (2006).

Figure 3: Rural Usage of LPG, Charcoal and Firewood for Cooking



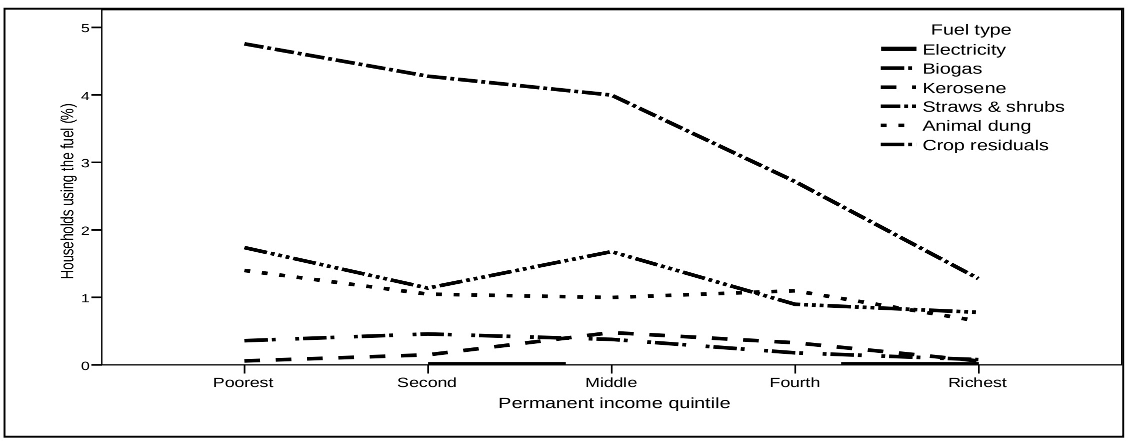
Source: Plot based on SHHS (2006).

Figure 4: Urban Usage of Marginal Cooking Fuels



Source: Plot based on SHHS (2006).

Figure 5: Rural Usage of Marginal Cooking Fuels



Source: Plot based on SHHS (2006).

Table 1: Household's Socioeconomic Characteristics

	Mean	Std. Dev.
Highest education of the household head /[1]		
1 if had primary education, else =0	0.215	0.411
1 if had post-primary education, else =0	0.118	0.323
Size of household: number of members	7.0	2.181
Age of the household head: number of years	51.6	17.732
Gender of the household head: 1 if male, female =0	0.775	0.418
The ratio of adult females in the household to household's size	0.230	0.125
Modern dwelling: 1 if roofing is metallic, cement fibre, concrete, shingle or brick, else =0	0.127	0.333
Cooking utensils: I if had cooking utensils, else =0	0.806	0.396
Cooking arrangement/[2]:		
1 if cook in separate room, else =0	0.530	0.499
1 if cook outdoors, else =0	0.308	0.462
Frequency of served meals per day: log number of meals served in the household	0.933	0.228
Permanent income quintile based on assets endowment/[3]:		
1 if belongs to the second income quintile, else =0	0.198	0.399
1 if belongs to the middle income quintile, else =0	0.202	0.401
1 if belongs to the fourth income quintile, else =0	0.201	0.400
1 if belongs to the richest income quintile, else =0	0.191	0.393
Forests endowment: 1 if the households resides in forest rich locality, else =0/[4]	0.539	0.499
Residence in urban area: 1 if resides in urban locality (with population size 5000 and more), else=0	0.280	0.449
Children under-five-years suspected for pneumonia: 1 if child case is reported, else =0	0.113	0.316
Use smokier fuels, (firewood, straws, dung and crop residuals): 1 if use smokier fuels, else =0	0.665	0.472

Notes: 1/. The category of post-primary education includes secondary, post-secondary diploma, university and higher. Uncompleted primary or non-educated is the reference category. 2/. Cooking in all-purpose room is the reference category. 3/. The poorest income quintile is the reference category. 4/. Forest endowment coding is extrapolated based on FAO (1999) and MET (2000).

Table 2: Summary of Distribution of Smokier Fuels Users by Cooking Habitat

	Cooking habitat				
Fuel adoption	**All-purpose room (%)**	**Separate room (%)**	**Outdoors (%)**	**Total (%)**	**Population in million**
National					
Use smokier fuels	14.8	27.6	24.1	66.5	19.96
Do not use smokier fuels	2.5	24.6	6.4	33.5	10.10
Total	17.3	52.2	30.5	100	30.06
Urban					
Use smokier fuels	8.8	15.4	12.5	36.7	3.33
Do not use smokier fuels	4.4	47.9	11.0	63.3	5.72
Total	13.2	63.3	23.5	100	9.05
Rural					
Use smokier fuels	17.4	32.8	29.1	79.3	16.63
Do not use smokier fuels	1.7	14.6	4.4	20.7	4.33
Total	19.1	47.4	33.5	100	20.96

Source: Calculation based on SHHS (2006).

Table 3: Summary of Distribution of Children Suspected for Pneumonia by Smokier Fuels Usage, Cooking Habitat and Location

Fuel adoption	All-purpose room (%)	Cooking habitat Separate room (%)	Outdoors (%)	Total (%)	Number of child cases in thousands
National					
Use smokier fuels	13.0	30.4	26.5	69.9	419.99
Do not use smokier fuels	3.6	17.4	9.1	30.1	181.26
Total	16.6	47.8	35.6	100	601.25
Urban					
Use smokier fuels	11.9	24.5	16.7	53.1	83.14
Do not use smokier fuels	6.2	30.3	10.4	46.9	93.95
Total	18.1	54.8	27.1	100	177.09
Rural					
Use smokier fuels	13.5	32.9	30.5	76.9	326.04
Do not use smokier fuels	2.5	12.0	8.6	23.1	98.12
Total	16.0	44.9	39.1	100	424.16

Source: Calculation based on SHHS (2006).

Table 4: Summary of Distribution of Children Suspected for Pneumonia by Smokier Fuels Usage, Cooking Habitat and Income Quintiles

Smokier fuel by income	All-purpose room (%)	Cooking habitat Separate room (%)	Outdoors (%)	Total (%)	Number of Children in thousands
Poorest income quintile					
Use smokier fuels	41.4	3.8	37.2	82.4	94.81
Do not use smokier fuels	11.8	1.0	4.8	17.6	20.16
Total	53.2	4.8	42.0	100	114.97
Second income quintile					
Use smokier fuels	11.9	31.1	30.4	73.4	92.10
Do not use smokier fuels	4.6	14.8	7.2	26.6	33.28
Total	16.5	45.9	37.6	100	125.38
Middle income quintile					
Use smokier fuels	10.7	41.3	18.9	70.9	97.53
Do not use smokier fuels	1.1	20.7	7.3	29.1	40.23
Total	11.8	62.0	26.2	100	137.76
Fourth income quintile					
Use smokier fuels	0.8	35.8	28.0	64.6	76.33
Do not use smokier fuels	0.6	22.2	12.6	35.4	41.75
Total	1.4	58.0	40.6	100	118.08
Richest income quintile					
Use smokier fuels	0.1	38.2	18.1	56.4	59.21
Do not use smokier fuels	0.0	28.9	14.7	43.6	45.84
Total	0.1	67.1	32.8	100	105.05

Source: Calculation based on SHHS (2006).

Table 5: The Average Marginal Effects of The Factors Driving the Alternative Fuel Choices in Sudan

	Model (I): Average Marginal Effects (AMEs)								**Model (II): Average Marginal Effects (AMEs)**				
Variables	**LPG**	**Biogas**	**Kerosene**	**Charcoal**	**Wood**	**Straws**	**Animal Dung**	**Crop residuals**	**LPG**	**Charcoal**	**Wood**	**Straws**	**Dung/ residuals**
Constant	**0.1408**	-0.0087	**0.0296**	-0.0972	**0.3238**	**-0.3382**	**-0.0234**	**-0.0267**	**0.2182**	-0.1300	**0.2902**	**-0.3392**	**-0.0391**
Primary education level	**0.0620**	-0.0012	**0.0037**	**0.1322**	**-0.1847**	**-0.0036**	**-.0040**	**-0.0044**	**0.0628**	**0.1352**	**-0.1860**	**-0.0037**	**-0.0082**
Post-primary education level	**0.0695**	**0.0013**	**0.0043**	**0.1748**	**-0.2233**	**-0.0106**	-0.0003	**-0.0157**	**0.0730**	**0.1768**	**-0.2313**	**-0.0110**	**-0.0076**
Size of household	**-0.0234**	**-0.0055**	**-0.0032**	**-0.0057**	**0.0095**	**0.0210**	0.0023	**0.0050**	**-0.0319**	**-0.0056**	**0.0093**	**0.0210**	**0.0072**
Age of the household head	**-0.0655**	**-0.0026**	**-0.0123**	**0.0095**	**0.0122**	**0.0627**	-0.0010	-0.0030	**-0.0810**	**0.0096**	**0.0128**	**0.0628**	-0.0041
Gender of the household head	-0.0050	**0.0048**	-0.0004	-0.0016	-0.0177	**0.0098**	**0.0059**	**0.0042**	-0.0005	-0.0020	-0.0173	**0.0098**	**0.0099**
Number of adult females	**-0.0598**	-0.0035	**-0.0059**	**-0.0030**	**0.0787**	-0.0169	0.0079	0.0025	**-0.0715**	**-0.0018**	**0.0798**	-0.0168	0.0104
Type of Dwelling (modern roof)	**0.0616**	**0.0088**	**0.0067**	**0.0023**	**-0.0758**	0.0026	0.0019	**-0.0081**	**0.0752**	**0.0022**	**-0.0773**	0.0025	-0.0026
Availability of Cooking utensils	**0.0130**	**0.0084**	0.0011	**0.0090**	**-0.0094**	**-0.0156**	**-0.0052**	-0.0013	**0.0218**	**0.0088**	**-0.0084**	**-0.0156**	**-0.0067**
Cooking in a separate room	0.0115	**0.0040**	0.0017	**0.0074**	**0.0161**	-0.0301	**-0.0004**	-0.0102	**0.0157**	**0.0084**	**0.0165**	-0.0300	**-0.0106**
Cooking outdoors	-0.0080	**-0.0044**	-0.0017	-0.0117	0.0189	**-0.0011**	0.0063	**0.0017**	**-0.0164**	-0.0099	0.0202	**-0.0011**	**0.0071**
Frequency of meals per day	0.0192	0.0037	-0.0008	**-0.0686**	**0.0416**	0.0072	**-0.0058**	0.0035	0.0200	**-0.0669**	**0.0421**	0.0073	-0.0024
Permanent income level													
The second income quintile	-0.0157	-0.0024	**0.0071**	**0.0806**	**-0.0635**	-0.0025	0.0005	**-0.0041**	-0.0082	**0.0791**	**-0.0646**	-0.0025	-0.0038
The middle income quintile	**0.0288**	**-0.0049**	**0.0036**	**0.0257**	**-0.0547**	0.0020	-0.0005	0.0000	**0.0130**	**0.0355**	**-0.0502**	0.0021	-0.0004
The third income quintile	**0.0336**	**-0.0149**	-0.0006	**0.0413**	**-0.0625**	0.0022	0.0024	-0.0015	0.0047	**0.0517**	**-0.0599**	0.0022	0.0013
The richest income quintile	**0.0507**	**-0.0215**	-0.0057	**0.0705**	**-0.1087**	0.0046	0.0042	**0.0059**	**0.0178**	**0.0772**	**-0.1086**	0.0045	**0.0091**
Forests endowment	**-0.1131**	**-0.0044**	-0.0030	**-0.0625**	**0.1997**	**-0.0115**	**-0.0050**	-0.0002	**-0.1131**	**-0.0685**	**0.1985**	**-0.0116**	**-0.0053**
Residence in urban area	**0.0248**	**0.0003**	**0.0040**	**0.1715**	**-0.1941**	**-0.0079**	-0.0004	0.0018	**0.0290**	**0.1719**	**-0.1945**	**-0.0079**	0.0014
Number of observations	19716	19716	19716	19716	19716	19716	19716	19716	19716	19716	19716	19716	19716

Source: Calculation based on Appendix Tables 3, 6, 9 and sample numbers

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A. Appendix: Tables

Appendix Table 1: Summary of the components

	Components						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Television	0.788	0.514	0.324	0.142	0.272	0.231	0.085
Radio	0.626	0.274	0.026	-0.268	0.163	0.416	0.022
Refrigerator	0.641	0.552	0.436	0.176	0.186	0.122	0.040
Bicycle	0.245	0.407	-0.023	-0.413	0.243	0.417	-0.245
Rooms no.	0.781	0.315	0.153	-0.116	0.234	0.166	0.044
Motorcycle	0.121	0.087	0.210	0.005	0.445	0.104	-0.066
Computer	0.174	0.184	0.766	0.021	0.269	0.046	-0.012
Net-connection	0.316	0.268	0.766	0.074	0.018	0.111	0.045
Car/truck	0.155	0.094	0.082	-0.010	0.690	0.116	0.030
Boot	0.156	0.151	0.052	0.029	0.679	-0.059	0.040
Fix-telephone	0.551	0.535	0.275	0.068	0.286	0.160	-0.028
Land Ownership	0.631	0.178	0.062	-0.425	0.173	0.254	0.192
Carpeted floor	0.313	0.807	0.229	0.031	0.069	0.090	0.082
Modern toilet	0.681	0.398	0.239	0.206	0.162	0.072	-0.064
Non-shared toilet	0.475	0.130	0.081	-0.043	0.049	0.117	0.217
Employed	0.066	0.093	0.146	0.070	-0.076	0.665	-0.058
Resident	0.171	0.147	0.103	0.746	0.076	0.076	0.022
Connected to water source	0.688	0.355	0.266	0.152	0.116	0.066	0.106
Mobile	0.645	0.463	0.383	0.136	0.275	0.202	0.065
Watch	0.250	0.208	0.097	-0.366	0.108	0.567	0.506
Have cooking utensils	0.147	0.124	0.057	0.072	0.049	0.020	0.801
Have modern roof	0.454	0.820	0.187	0.011	0.198	0.155	0.065
Cart	0.070	-0.038	-0.163	0.023	0.231	0.416	0.140
Meals served	0.590	0.221	0.025	-0.405	0.149	0.016	-0.139

Source: Author’s calculation based on SHHS (2006).

Appendix Table 2: The Distribution of Primary Cooking Fuels by States

State	Electricity (%)	LPG & Natural gas (%)	Biogas (%)	Kerosene (%)	Charcoal (%)	Wood (%)	Straw/ shrubs/ grass (%)	Animal dung (%)	Crop residuals (%)	Other (%)	Missing (%)	Total (%)	Solid fuels* (%)	Number surveyed households
Northern	0.0	3.2	0.0	0.1	6.4	44.7	2.1	0.0	0.0	43.1	0.3	100.0	53.2	997
River Nile	0.1	11.7	0.0	0.7	3	17.6	0.5	0.1	0.0	66.1	0.2	100.0	21.1	990
Red Sea	0.0	13.5	0.4	0.1	33	27.0	5.5	0.1	0.0	19.3	1.0	100.0	65.6	986
Kassala	0.0	2.6	0.0	0.1	19.5	57.5	1.6	0.3	0.0	17.9	0.5	100.0	78.9	994
Gadarif	0.0	0.6	0.0	0.0	37.2	45.1	2.4	0.2	0.8	13.2	0.4	100.0	85.8	991
Khartoum	0.0	26.4	0.0	1.9	17.7	3.5	0.6	0.0	0.0	49.0	0.8	100.0	21.8	965
Gezira	0.1	0.1	0.0	0.0	18.4	8.1	1.1	1.8	0.0	70.1	0.3	100.0	29.4	997
Sinnar	0.2	15.9	0.0	0.2	37.5	27.9	3.8	2.1	0.0	12.1	0.3	100.0	71.3	993
Blue Nile	0.0	0	0.0	0.0	29.9	66.9	0.3	0.0	0.0	2.8	0.2	100.0	97.0	993
White Nile	0.1	8.5	0.0	0.6	22.2	29.8	2.6	5.3	0.0	30.5	0.5	100.0	59.9	998
N. Kordofan	0.0	3.7	0.0	0.1	21.4	66.7	0.6	0.0	0.0	7.4	0.2	100.0	88.7	992
S. Kordofan	0.0	0.1	0.1	0.1	19.5	78.3	0.3	0.0	0.0	0.8	0.7	100.0	98.1	963
North Darfur	0.0	0.9	0.0	0.0	11.6	85.4	0.8	0.2	0.0	0.6	0.4	100.0	98.1	982
West Darfur	0.4	0	0.0	0.1	5.6	85.9	5.4	0.0	0.0	1.7	0.8	100.0	97.0	993
South Darfur	0.0	0.5	0.0	0.0	14	84.5	0.2	0.0	0.0	0.7	0.1	100.0	98.7	992
Jonglei	0.5	0.7	0.1	0.0	4.6	68.4	19.0	0.4	4.1	0.7	1.4	100.0	96.5	956
Upper Nile	0.0	1.3	1.7	2.1	13.5	73.2	0.5	0.4	0.6	0.0	6.7	100.0	88.2	771
Unity	0.0	0.9	1.7	0.1	4.7	80.9	1.7	1.0	5.6	0.2	3.3	100.0	93.8	935
Warap	0.0	9.1	7.6	0.1	1.1	77.2	0.5	0.0	1.6	0.3	2.4	100.0	80.5	988
NBG	0.0	3.7	0.3	0.0	7.6	75.9	3.6	0.7	4.5	0.1	3.6	100.0	92.3	893
WBG	0.0	0.7	0.0	0.2	6.2	89.0	0.5	0.1	0.1	0.0	3.1	100.0	96.0	815
Lakes	0.0	2.8	0.1	0.1	1.8	91.7	1.0	0.1	0.1	0.1	2.1	100.0	94.8	980
W. Equatoria	0.0	0	0.0	0.0	0.8	98.6	0.1	0.0	0.0	0.0	0.6	100.0	99.4	898
C. Equatoria	0.3	0.2	0.0	0.1	8.3	88.9	0.0	0.0	0.3	0.3	1.5	100.0	97.6	986
E. Equatoria	0.0	0	0.0	0.5	5.5	91.6	0.1	0.0	0.0	0.0	2.3	100.0	97.2	998
Sudan	**0.1**	**6.0**	**0.4**	**0.4**	**15.6**	**53.7**	**2.0**	**0.5**	**0.5**	**19.7**	**1.0**	**100.0**	**72.4**	24046

Notes: * This variable aggregates wood, charcoal, crop residues and dung.
Source: Tabulation based on SHHS (2006).

Appendix Table 3: model 1: MNL Estimates of All Cooking Fuels Choices in Sudan

	Biogas	Kerosene	Charcoal	Firewood	Straws	Animal Dung	Crop residuals
Constant	-4.1134**	3.9893**	-3.0110***	-2.4939**	-17.2950***	-6.6174***	-7.0888***
	(1.7320)	(1.2142)	(1.0434)	(1.1594)	(1.2734)	(1.9312)	(1.6728)
Primary education level	-1.8412***	-0.2790	-0.6431***	-2.3155***	-2.2184***	-2.5155***	-2.7225***
	(0.3304)	(0. 2761)	(0.1157)	(0.1172)	(0.1618)	(0.3631)	(0.3686)
Post-primary education level	-1.6583***	-0.2795	-0.6292***	-2.7588***	-2.9056***	-2.3216***	-4.7846***
	(0.2248)	(0.3610)	(0.1481)	(0.1541)	(0.2586)	(0.3188)	(1.0388)
Size of household	-0.5193**	-0.3034	0.4171***	0.6109***	1.4945***	0.9245***	1.3536***
	(0.2475)	(0.1998)	(0.0775)	(0.0672)	(0.3098)	(0.3273)	(0.2181)
Age of the household head	0.8302***	-1.5354***	1.2620***	1.5652***	4.2086***	1.3688***	1.1467***
	(0.3216)	(0.3570)	(0.1749)	(0.1603)	(0.2163)	(0.3479)	(0.2832)
Gender of the household head	0.9768***	0.0055	0.0821	0.0829	0.5283***	0.9978***	0.7235**
	(0.2546)	(0.2801)	(0.0757)	(0.0960)	(0.1630)	(0.3324)	(0.3031)
Number of adult females	0.5678	-0.2949	1.0853***	1.5303***	0.7206	2.5391***	1.7955**
	(0.9194)	(0.6295)	(0.3138)	(0.3127)	(0.4797)	(0.5353)	(0.5642)
Type of Dwelling (modern roof)	0.3450	0.4420**	-1.1312***	-1.5943***	-1.3916***	-1.1457***	-2.6679***
	(0.3032)	(0.2016)	(0.1342)	(0.1442)	(0.2502)	(0.3287)	(0.5846)
Availability of Cooking utensils	1.12532***	0.0416	-0.2134	-0.3798***	-1.0332***	-1.1398***	-0.5747**
	(0.4241)	(0.4126)	(0.1450)	(0.1260)	(0.3510)	(0.3100)	(0.2229)
Cooking in a separate room	0.4717	0.1900	-0.1934	-0.3020	-1.6042***	-0.3955	-1.8442***
	(0.5588)	(0.6878)	(0.2878)	(0.2512)	(0.3091)	(0.5815)	(0.5777)
Cooking outdoors	-0.6099	-0.2221	0.1099	0.2839	0.2173	1.1964**	0.5218
	(0.4535)	(0.5822)	(0.2251)	(0.1884)	(0.2455)	(0.5295)	(0.5026)
Frequency of meals per day	0.4863	-0.4100	-0.5962***	-0.0529	0.1891	-1.0047**	0.3783
	(0.7697)	(0.7279)	(0.1831)	(0.2450)	(0.5065)	(0.4462)	(0.6860)
Permanent income level							
The second income quintile	-0.3770	1.6509	0.5573	-0.1603	-0.1775	0.0475	-0.6844
	(0.7912)	(1.3211)	(0.6268)	(0.7351)	(0.7989)	(0.7516)	(0.8603)
The middle income quintile	-1.5491*	0.2744	-0.4298	-0.8645	-0.7053	-0.8199	-0.7932*
	(0.8251)	(1.2585)	(0.5590)	(0.7072)	(0.7276)	(0.7154)	(0.8326)
The third income quintile	-3.5083***	-0.6928	-0.4381	-1.0032	-0.8188	-0.4940	-1.1422
	(0.9012)	(1.3067)	(0.5107)	(0.6889)	(0.7334)	(0.6893)	(0.8456)
The richest income quintile	-5.2131***	-2.0454**	-0.6176	-1.5400**	-1.1847	-0.6689	-0.4986
	(0.9091)	(1.3571)	(0.4842)	(0.6544)	(0.7644)	(0.6362)	(0.8664)
Forests endowment	1.6491***	1.1477***	1.8219***	3.1860***	2.4262***	1.9929***	2.8965***
	(0.4688)	(0.3908)	(0.3154)	(0.4060)	(0.3726)	(0.4065)	(0.4026)
Residence in urban area	-0.9415***	0.3547	0.1676*	-1.6783***	-1.7384***	-1.3281***	-1.1621***
	(0.2755)	(0.2689)	(0.0886)	(0.0851)	(0.1906)	(0.2089)	(0.2543)
Number of observations	19716	19716	19716	19716	19716	19716	19716

Notes: In likelihood =-13814.6640. χ^2 (119 DF) =11931.9159; significance level, 0.0000. Pseudo R-squared = 0.3016. Normalized AIC =1.4142; Normalized SBC=1.4646 and Normalized HQ= 1.43071/. The dependent variable is the given fuel choice, LPG is the reference category. The z-statistics significance level: *: 10%, **: 5% and ***: 1%.
Source: Author's calculation based on SHHS (2006).

Appendix Table 4: Hausman and McFadden IIA Test for Model (I)[3]

Omitted alternative	χ^2	**DF**	$P>\chi^2$	**Evidence**[/1]
LPG	-37.188	108	--	for H_0[/2]
Biogas	139.249	108	0.023	against H_0
Kerosene	-32.637	108	--	for H_0
Charcoal	484.420	108	0.000	against H_0
Firewood	-46561.170	108	--	for H_0
Straws	-1.351	108	--	for H_0
Animal Dung	55.464	108	0.999	for H_0
Crop residuals	61.253	108	0.999	for H_0

Notes: 1. H_0: Odds (alternative-j versus alternative-k) are independent from the other alternatives. 2. $\chi^2<0$ indicates that the estimated model does not satisfy asymptomatic assumptions of the test, and is a strong evidence against rejecting the null hypothesis (Hausman and McFadden 1984, 1226 footnote 4).
Source: Author's calculation based on estimation results, SHHS (2006).

[3] Both Hausman and Small-Hsiao tests are extensively used to examine the IIA, however, the former test is easier to compute. Its test statistic is $\chi^2 = (\hat{\beta}_r - \hat{\beta}_f)'[\hat{V}_r - \hat{V}_f]^{-1}(\hat{\beta}_r - \hat{\beta}_f)$ where *r* and *f* denotes estimates based, respectively, on the restricted model- obtained by omitting a given alternative- and the full models, $\hat{\beta}$'s are the estimated coefficients and $\hat{V}$'s are the estimates of the asymptotic covariance matrixes. The statistic has a chi-squared distribution with k degrees of freedom, where k equal rank $(\hat{V}_r - \hat{V}_f)$.

Appendix Table 5: Sequential Pair-Wise Tests for Pooling Fuel Options: Model (I)[4]

Pooled alternative	χ^2	DF	$P>\chi^2$	Evidence[/1]
LPG and Biogas	394.369	17	0.000	against H_0
LPG and Kerosene	164.559	17	0.000	against H_0
LPG and Charcoal	1336.476	17	0.000	against H_0
LPG and Firewood	63877.774	17	0.000	against H_0
LPG and Straws	2554.106	17	0.000	against H_0
LPG and Animal Dung	608.146	17	0.000	against H_0
LPG and Crop residuals	862.382	17	0.000	against H_0
Biogas and Kerosene	108.716	17	0.000	against H_0
Biogas and Charcoal	256.651	17	0.000	against H_0
Biogas and Firewood	285.282	17	0.000	against H_0
Biogas and Straws	410.817	17	0.000	against H_0
Biogas and Animal Dung	176.720	17	0.000	against H_0
Biogas and Crop residuals	237.367	17	0.000	against H_0
Kerosene and Charcoal	177.434	17	0.000	against H_0
Kerosene and Firewood	538.437	17	0.000	against H_0
Kerosene and Straws	630.387	17	0.000	against H_0
Kerosene and Animal Dung	271.744	17	0.000	against H_0
Kerosene and Crop residuals	380.072	17	0.000	against H_0
Charcoal and Firewood	6327.582	17	0.000	against H_0
Charcoal and Straws	1532.653	17	0.000	against H_0
Charcoal and Animal Dung	260.333	17	0.000	against H_0
Charcoal and Crop residuals	410.183	17	0.000	against H_0
Firewood and Straws	629.654	17	0.000	against H_0
Firewood and Animal Dung	109.475	17	0.000	against H_0
Firewood and Crop residuals	98.057	17	0.000	against H_0
Straws and Animal Dung	147.547	17	0.000	against H_0
Straws and Crop residuals	150.332	17	0.000	against H_0
Animal Dung and Crop residuals	57.167	17	0.000	against H_0

Notes: 1. H_0: The given alternatives can be merged.
Source: Author's calculation based on estimation results and sample numbers, SHHS (2006).

[4] Under Cramer-Ridder test; the null hypothesis that the alternatives can be pooled has the following form: $LR = 2(\log \hat{L} - \log \hat{L}_R) \sim\chi^2$ with k degrees of freedom; where $\log \hat{L}$ is the maximum likelihood of the full parameters model; $\log \hat{L}_R$ is the maximum likelihood of the pooled parameters in the restricted model and k is the number of the coefficients. For two alternatives 1 and 2 $\log \hat{L}_R = n_1 \log n_1 + n_2 \log n_2 - n \log n + \hat{L}$, where n is the share of alternatives 1 and 2, respectively, in total observations and $n = n_1 + n_2$.

Appendix 1 Table 6: Model II: MNL Estimates of the Main Cooking Fuels Choices in Sudan

	Charcoal	Firewood	Straws	Dung /Crop residuals
Constant	-3.9011***	-3.3588***	-18.1554***	-6.8510***
	(0.8161)	(0.9382)	(1.0731)	(1.4530)
Primary education level	-0.4356***	-2.0992***	-2.0038***	-2.3949***
	(0.1120)	(0.1055)	(0.1387)	(0.2846)
Post-primary education level	-0.4314***	-2.5509***	-2.6998***	-2.7208***
	(0.1458)	(0.1558)	(0.2628)	(0.3056)
Size of household	-0.4708***	0.6694***	1.5528***	1.1928***
	(0.0754))	(0.0732)	(0.3209)	(0.2266)
Age of the household head	1.2888***	1.5859***	4.2283***	1.2721***
	(0.1690)	(0.1519)	(0.2119)	(0.2651)
Gender of the household head	0.0007	-0.0818	0.4373***	0.7577***
	(0.0770)	(0.0709)	(0.1546)	(0.2715)
Number of adult females	1.0883***	1.5291***	0.7191	2.1599***
	(0.2889)	(0.2769)	(0.4642)	(0.4235)
Type of Dwelling (modern roof)	-1.1449***	-1.6042***	-1.4018***	-1.6630***
	(0.1311)	(0.1348)	(0.3403)	(0.3128)
Availability of Cooking utensils	-0.3022**	-0.4816***	-1.1344***	-0.9677***
	(0.1374)	(0.1225)	(0.2008)	(0.1915)
Cooking in a separate room	-0.2124	-0.3255	-1.6263***	-1.1514***
	(0.2439)	(0.2236)	(0.3425)	(0.4736)
Cooking outdoors	0.2122	0.3932**	0.3261	0.8892**
	(0.2073)	(0.1776)	(0.2675)	(0.4294)
Frequency of meals per day	-0.5669***	-0.0379	0.2057	-0.2864
	(0.2134)	(0.2776)	(0.4834)	(0.4377)
Permanent income level				
The second income quintile	0.4348	-0.2774	-0.2938	-0.4473
	(0.4523)	(0.5458)	(0.5268)	(0.5004)
The middle income quintile	-0.0606	-0.4843	-0.3258	-0.4283
	(0.3921)	(0.5398)	(0.4559)	(0.4922)
The third income quintile	0.1298	-0.4063	-0.2261	-0.2070
	(0.3429)	(0.4999)	(0.4276)	(0.4868)
The richest income quintile	0.0292	-0.8486	-0.5006	0.0175
	(0.3303)	(0.5281)	(0.5062)	(0.4893)
Forests endowment	1.4667***	2.8195***	2.0596***	2.0797***
	(0.2489)	(0.3421)	(0.2914)	(0.2972)
Residence in urban area	0.2254***	-1.6096***	-1.6702***	-1.1726***
	(0.0824)	(0.0779)	(0.1966)	(0.1675)
Number of observations	19716	19716	19716	19716

Notes: In likelihood =-13143.9885. χ^2 (68 DF) = 11342.2361; significance level, 0.0000. Pseudo R-squared = 0.3014. Normalized AIC = 1.3406; Normalized SBC= 1.3695 and Normalized HQ= 1.35011/. The dependent variable is the given fuel choice, LPG is the reference category. The z-statistics significance level: *: 10%, **: 5% and ***: 1%.
Source: Author calculation based on SHHS (2006).

Appendix Table 7: Hausman and McFadden IIA Test for Model II

Omitted alternative	χ^2	DF	$P>\chi^2$	Evidence[/1]
LPG	-6.979	54	--	for H_0[/2]
Charcoal	16.431	54	1.000	for H_0
Firewood	-24.317	54	0.999	for H_0
Straws	32.414	54	0.999	for H_0
Dung and residuals	-44.386	54	--	for H_0

Notes: 1. H_0: Odds (alternative-j versus alternative-k) are independent from the other alternatives.
2. χ^2<0 indicates that the estimated model does not satisfy asymptomatic assumptions of the test, and is a strong evidence against rejecting the null hypothesis (Hausman and McFadden 1984,1226 footnote 4).
Source: Author's calculation based on estimation results, SHHS (2006).

Appendix Table 8: Sequential Pair-Wise Tests of Pooling Fuel Options: Model II

Pooled alternative	χ^2	**DF**	**P>χ^2**	**Evidence**[/1]
LPG and Charcoal	18413.430	17	0.000	against H_0
LPG and Firewood	10206.810	17	0.000	against H_0
LPG and Straws	2430.272	17	0.000	against H_0
LPG and Dung & residuals	612.098	17	0.000	against H_0
Charcoal and Firewood	144119.800	17	0.000	against H_0
Charcoal and Straws	30881.100	17	0.000	against H_0
Charcoal and Dung & residuals	17817.090	17	0.000	against H_0
Firewood and Straws	1415.580	17	0.000	against H_0
Firewood and Dung & residuals	70.243	17	0.000	against H_0
Straws and Dung & residuals	183.234	17	0.000	against H_0

Notes: 1. H_0: The given alternatives can be merged.

Source: Author’s calculation based on estimation results and sample numbers, SHHS (2006).

Appendix Table 9: The Marginal Effects of the Factors Driving the Alternative Fuel Choices in Sudan

	Model (I): Marginal Effects (MEs)								Model (II): Marginal Effects (MEs)				
Variables	**LPG**	**Biogas**	**Kerosene**	**Charcoal**	**Firewood**	**Straws**	**Animal Dung**	**Crop residuals**	**LPG**	**Charcoal**	**Firewood**	**Straws**	**Dung/ Crop residuals**
Constant	0.0330***	-0.0038	0.0074***	-0.0350	0.2443***	-0.2013***	-0.0247***	-0.0186***	0.0770***	-0.0457	0.2113***	-0.2013***	-0.0413***
	(0.0069)	(0.0040)	(0.0020)	(0.0430)	(0.0468)	(0.0131)	(0.0080)	(0.0058)	(0.0107)	(0.0426)	(0.0473)	(0.0131)	(0.0109)
Primary education level	0.0236***	0.0005	0.0019***	0.2289***	-0.2455***	-0.0030*	-0.0033*	-0.0031**	0.0378***	0.2248***	-0.2515***	-0.0031*	-0.0079***
	(0.0020)	(0.0008)	(0.0005)	(0.0074)	(0.0082)	(0.0019)	(0.0017)	(0.0013)	(0.0025)	(0.0073)	(0.0083)	(0.0019)	(0.0025)
Post-primary education level	0.0278***	0.0021**	0.0023***	0.2927***	-0.3072**	-0.0077**	0.0003	-0.0105***	0.0456***	0.2870***	-0.3176***	-0.0077**	-0.0074**
	(0.0024)	(0.0009)	(0.0006)	(0.0096)	(0.0112)	(0.0031)	(0.0020)	(0.0035)	(0.0030)	(0.0095)	(0.0112)	(0.0031)	(0.0036)
Size of household	-0.0069***	-0.0032***	-0.0010**	-0.0281***	0.0209**	0.0126***	0.0022	0.0033**	-0.0136***	-0.0285***	0.0224**	0.0126***	0.0071***
	(0.0013)	(0.0009)	(0.0004)	(0.0098)	(0.0106)	(0.0023)	(0.0019)	(0.0013)	(0.0021)	(0.0097)	(0.0108)	(0.0023)	(0.0026)
Age of the household head	-0.0179***	-0.0020**	-0.0034***	-0.0441***	0.0325***	0.0373***	-0.0010	-0.0016	-0.0326***	-0.0412***	0.0399***	0.0373***	-0.0034
	(0.0019)	(0.0009)	(0.0007)	(0.0099)	(0.0106)	(0.0025)	(0.0018)	(0.0012)	(0.0027)	(0.0098)	(0.0108)	(0.0025)	(0.0024)
Gender of the household head	-0.0012	0.0025***	-0.0001	-0.0029	-0.0129	0.0059***	0.0058***	0.0027**	-0.0002	-0.0015	-0.0139	0.0059**	0.0096***
	(0.0010)	(0.0008)	(0.0003)	(0.0077)	(0.0083)	(0.0017)	(0.0019)	(0.0011)	(0.0017)	(0.0076)	(0.0084)	(0.0017)	(0.0023)
Number of adult females	-0.0168***	-0.0025	-0.0019*	-0.0578**	0.0801***	-0.0097	0.0072	0.0016	-0.0301***	-0.0555**	0.0858***	-0.0097	0.0095
	(0.0038)	(0.0028)	(0.0011)	(0.0269)	(0.0289)	(0.0062)	(0.0047)	(0.0033	(0.0062)	(0.0266))	(0.0293)	(0.0062)	(0.0067)
Type of Dwelling (modern roof)	0.0175***	0.0053***	0.0021***	0.0601***	-0.0835***	0.0012	0.0022	-0.0051**	0.03166***	0.0580***	-0.0887***	0.0012	-0.0022
	(0.0017)	(0.0010)	(0.0005)	(0.0100)	(0.0113)	(0.0032)	(0.0021)	(0.0025)	(0.0024)	(0.0100)	(0.0115)	(0.0032)	(0.0035)
Availability of Cooking utensils	0.0042***	0.0046***	0.0004	0.0242***	-0.0180**	-0.0094***	-0.0051***	-0.0009	0.0097***	0.0259***	-0.0196**	0.0094***	-0.0066***
	(0.0013)	(0.0013)	(0.0004)	(0.0083)	(0.0088)	(0.0015)	(0.0012)	(0.0009)	(0.0022)	(0.0082)	(0.0090)	(0.0015)	(0.0018)
Cooking in a separate room	0.0036	0.0022**	0.0005	0.0184	0.0007	-0.0180***	-0.0006	-0.0067***	0.0070**	0.0194	0.0022	-0.0180***	-0.0105***
	(0.0023)	(0.0010)	(0.0005)	(0.0124)	(0.0133)	(0.0024)	(0.0023)	(0.0016)	(0.0035)	(0.0123)	(0.0134)	(0.0024)	(0.0029)
Cooking outdoors	-0.0030	-0.0025**	-0.0005	-0.0242**	0.0235*	-0.0005	0.0061***	0.0012	-0.0076**	-0.0247**	0.0261**	-0.0005	0.0068***
	(0.0024)	(0.0010)	(0.0005)	(0.0118)	(0.0124)	(0.0017)	(0.0020)	(0.0010)	(0.0035)	(0.0117)	(0.0125)	(0.0017)	(0.0023)
Frequency of meals per day	0.0017	0.0018	-0.0003	-0.0761***	0.0716***	0.0046	-0.0056*	0.0023	0.0027	-0.0739***	0.0687***	0.0046	-0.0021
	(0.0028)	(0.0016)	(0.0006)	(0.0183)	(0.0196)	(0.0036)	(0.0030)	(0.0022)	(0.0045)	(0.0182)	(0.0199)	(0.0036)	(0.0043)
Permanent income level													
The second income quintile	0.0004	-0.0010	0.0185***	0.1000***	-0.0971***	-0.0019	0.0006	-0.0028**	0.0033	0.0987***	-0.0963***	-0.0019	-0.0038
	(0.0031)	(0.0010)	(0.0007)	(0.0129)	(0.0136)	(0.0021)	(0.0019)	(0.0013)	(0.0041)	(0.0128)	(0.0138)	(0.0021)	(0.0026)
The middle income quintile	0.0092***	-0.0022**	0.0115*	0.0587***	-0.0675***	0.0010	-0.0003	-0.00001	0.0085**	0.0568***	-0.0660***	0.0010	-0.0004
	(0.0027)	(0.0011)	(0.0007)	(0.0137)	(0.0145)	(0.0023)	(0.0021)	(0.0013)	(0.0039)	(0.0136)	(0.0146)	(0.0023)	(0.0028)
The third income quintile	0.0106***	-0.0075***	0.0022	0.0773***	-0.0832***	0.0011	0.0026	-0.0011	0.0064	0.0724***	-0.0812***	0.0011	0.0012
	(0.0028)	(0.0016)	(0.0007)	(0.0148)	(0.0157)	(0.0027)	(0.0023)	(0.0016)	(0.0041)	(0.0147)	(0.0159)	(0.0027)	(0.0032)
The richest income quintile	0.0016***	-0.0108***	-0.0008	0.1252***	-0.1404***	0.0023	0.0045	0.0037**	0.0142***	0.1167***	-0.1419***	0.0023	0.0089**
	(0.0030)	(0.0019)	(0.0008)	(0.0163)	(0.0175)	(0.0035)	(0.0028)	(0.0019)	(0.0043)	(0.0161)	(0.0177)	(0.0035)	(0.0039)
Forests endowment	-0.0340***	-0.0036***	-0.0019	-0.1800***	0.2329***	-0.0063***	-0.0058***	0.00001	-0.0534***	-0.1752***	0.2404***	-0.0063***	-0.0056***
	(0.0023)	(0.0008)	(0.0004)	(0.0066)	(0.0074)	(0.0014)	(0.0012)	(0.0008)	(0.0027)	(0.0065)	(0.0071)	(0.0014)	(0.0017)
Residence in urban area	0.0158***	0.0012*	0.0019***	0.2534***	-0.2675***	-0.0056***	0.00001	0.0008	0.0268***	0.2492***	-0.2716***	-0.0056***	0.0012
	(0.0015)	(0.0006)	(0.0004)	(0.0067)	(0.0074)	(0.0018)	(0.0014)	(0.0009)	(0.0020)	(0.0067)	(0.0075)	(0.0018)	(0.0019)
Number of observations	19716	19716	19716	19716	19716	19716	19716	19716	19716	19716	19716	19716	19716

Source: Calculation based on Appendix Tables 3, 6 and sample numbers.