HOUSEHOLD ENERGY DEMAND IN UGANDA: ESTIMATION AND POLICY RELEVANCE

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Abstract

The generation capacity of electricity in Uganda is much higher than its demand, therefore, it is necessary to use this opportunity, to increase the usage of electricity at household level, hence improving their welfare. This article uses the Uganda Living Standards Measurement Study (LSMS) household data, to explore measures of increasing electricity usage in the country. The study applies a two-stage procedure, using probit model that describes the consumption selection decisions in the first stage, and, augmented Quadratic Almost Ideal Demand system (QUAIDs) model in the second stage, from which price and income elasticities are derived. From the probit model, we find that increased education level, income and living in urban areas increases the probability of using electricity while reducing that of firewood. We also find that though both the estimated Marshallian and Hicksian own-price elasticities are negative, the cross elasticities are different, indicating the presence of substitution effect. The results also indicate that electricity is a substitute of kerosene, charcoal and firewood, though not necessarily vice versa.

Keywords: Energy types, Elasticities, renewable energy, fuel stacking

1 Introduction

Electricity is critical to the welfare of households, and past studies showed its importance in the development process, as a component in the production functions (Beenstock et al., 1999; Ucan et al., 2014). The benefits of electricity include; improved household welfare, economic development, prevention of environmental degradation, and protection of human health since indoor pollution is prevented. Pollution from cooking with charcoal or firewood is a serious health hazard in many societies. Nevertheless, 13% of the world population still lack access to electricity, the majority of which live in the Sub-Saharan African region (IEA, 2019). In Uganda, only 22% of the households were connected to the grid electricity in 2015, majority of which lived in urban areas (UBOS, 2015).

Several households who have access to the electricity grid are not connected, and many of those connected use little electricity, in most cases using it only for lighting. Without electricity, households use other types of energy which include; firewood, kerosene, and charcoal to meet their daily energy needs. In fact, the past surveys in Uganda show that firewood is the most popular source of energy for cooking while kerosene dominates lighting (Uganda Bureau of Statistics (UBOS), 2014)

Uganda has implemented several programs to improve the supply and accessibility of electricity in the rural areas of the country, e.g. the Uganda's Rural Electrification Project (REP). UBOS (2014) data indicates that 75% of the Ugandan households used kerosene for lighting, while 87% used firewood and charcoal for cooking. Only 14% of the households used electricity for lighting and 1% used it for cooking. A clear indicator that majority of the population are not connected to the electricity grid in the country. In Uganda, like many African countries, many households find electricity too expensive to connect to the grid, even when they have access (Blimpo & Cosgrove-Davies, 2019).

Currently, in Uganda the generation capacity of electricity is higher than the demand. According to The Electricity Regulatory Authority (ERA), the installed generation capacity was 1240 MW, while total peak demand in 2019 was 724 MW (ERA 2020). Both numbers refer to production and consumption connected to the national grid. There are also several systems not connected to the national grid, both hydro power and solar, with a total installed capacity of in excess of 5MW.

Total power generated to the grid only in 2018 was 4085 GWh, of which 89% was hydro power. Exports of electricity were 233 GWh (6% of production) in 2018, while imports were 39 GWh in the same year (ERA 2020).

From a social point of view, the mismatch between generation capacity and demand represents a waste. Water is running through hydropower plants without generating electricity. There seems to be an opportunity to increase people's welfare and reduce environmental degradation from charcoal and firewood use by using the surplus electricity.

When the supply capacity is higher than demand, one would expect the price to go down, however, electricity prices in Uganda are not determined in a market, based on supply and demand. Project lenders and investors expect a reasonable power sale prices, allowing adequate risk related returns and with an enough margin to withstand changes in external conditions. All these are specified in the Power Purchasing Agreement (PPA) between the project company and the government. The PPA specifies a framework for the dispatch of the plant and the supply of power in accordance with the utility's requirements, a mechanism through which the project sponsors will recover a reasonable return on their investment and allocation risk between the parties. The rationale is that, if prices were market determined they would be too low to finance the system (Blimpo & Cosgrove-Davies, 2019). Tariffs are regularly adjusted by the ERA based on formulae intended to reflect changes in costs (fixed capacity and energy charge).

There are also important constrains related to electricity transmission. Many households, firms, and public agencies that would otherwise use electricity do not have access to supplies through the grid. Further expansion of the grid should contribute to increasing demand.

Off-grid solar power is expanding, but there are still few households and firms using this in Uganda. The data LSMS 2013/2014 shows that only 6% used solar energy in the country.

The paper aims at finding incentives to increase electricity usage. It can be done through, *inter alia*, the expansion of the transmission lines, expansion of the industrial sector, and increase the demand of households already connected. This can be achieved through lower prices. Estimating price and income elasticities will give us insight into the effects of lower prices.

For households, the cost of using electricity consists of several elements: the connection fee, the variable user fee and the cost of buying electric equipment (cables and appliances). We also not that many people have houses that do not have comply to the required standards that electricity can be safely installed (Blimpo & Cosgrove-Davies, 2019).

The paper will, therefore, contribute to the debate of price and expenditure elasticities of energy fuels in Uganda. In this study, we estimate the income and price elasticities of household demand for energy fuels, with the aim of providing incentives to increase the demand and usage of clean fuels, specifically electricity at household level, hence improving their welfare. It is at this level that the actual determinants of household energy consumption are found. We note that, analysis related to energy consumption, and household welfare, requires knowledge of households' demand responses to changes in price, and income. For instance, a policy aimed at proving subsidies either directly or indirectly to (vulnerable) household consumers requires this knowledge.

On the other hand, energy utilities may also require this knowledge of the price elasticities of the demand of energy in order to make dispatch decisions (in the case of electricity). The government can use these elasticities to assess the impact of the subsidies on the welfare of households. For instance, a policy aimed at adjusting the tariff structure towards more market determined prices, requires this knowledge. We also analyze income elasticities as (Blimpo & Cosgrove-Davies, 2019; Ngui et al., 2011) noted that household income must be increased beyond a certain point for households to completely shift to using a new fuel type.

There is limited literature on changes on energy consumption due to changes in income, and prices in Uganda. This may be due to lack of the extensive data required on consumer purchases and income flow. While this data is forthcoming in the country via regular household expenditure surveys, it is not readily available. In fact, most studies on developing countries rely on general household surveys, which often lack detailed information on household purchases, particularly, prices (Deaton, 1988; Deaton, 1997; Deaton & Grosh, 2000). This therefore limits the extent and quality of analysis required to influence policy in the respective countries. Due to similar constraints, we compute unit prices of charcoal, firewood and kerosene in this study.

This paper utilizes detailed Uganda 2013/2014 Living Standards Measurement Survey (LSMS) household data to analyze the household energy demand in the country and consequently, estimate the price and income (expenditure) elasticities. Using data on expenditure and prices of four energy groups of interest, we jointly estimate households' demand for these energy types using a Quadratic Almost Ideal Demand System (QUAIDS) developed by (Banks et al., 1997).

We find that, electricity is a substitute to the other energy types since its cross elasticities are positive. We notice that the Marshallian and Hicksian elasticities are different implying the presence of the income and substitution effect. We also find that all income elasticities of all energy fuels are greater than zero meaning energy is a normal good.

The rest of the paper is organized as follows: The next section, describes the Energy system in Uganda, Section three describes the model of demand systems and the empirical strategy used in the paper. The section also provides a description of the data used in the analysis. Results are presented and discussed in section four, and concluding remarks are given in section five. Finally, the recommendations are presented in section six.

2 The Electricity Sector in Uganda

Before 1997, the Uganda Electricity Board (UEB) was a monopoly. It managed: the generation, transmission and distribution of electricity. After unbundling UEB, there emerged three sectors all regulated by the Electricity Regulatory Authority (ERA), an independent body under the Electricity Act 1999. The three electricity sectors that emerged are;

A. The Uganda Electricity Generation Company Limited (UEGCL), which manages the electricity generation in the country. The installed electricity capacity in Uganda has grown rapidly, from just 400 MW in 2000 to 1240 MW today, 82% of which is hydro power (ERA, 2019) But in per capita terms this is still low. Uganda has a generation mix of energy sources i.e. Hydro, thermal, cogeneration with bagasse and grid-connected solar. Generation is carried out by more than 20 companies that are government owned, public-private partnerships and independent power producers. Their feed-in tariffs are set by ERA and they vary from company to company.

B. The Uganda Electricity Distribution Company Limited (UEDCL), which manages electricity distribution. This sector has many players and the aim is to eliminate monopoly hence improving on both efficiency and effectiveness resulting to fair price and consumer protection.

   There are currently nine distribution companies in Uganda, serving different geographical areas. Following liberalization of the sector, there has been a marked drop in energy losses, from 30% in 1999 to 16% in 2020, while the legally connected customer base has increased from 180 000 in 2001 to more than 1.6 million in 2020 (ERA, 2019).

C. The Uganda Electricity Transmission Company Limited (UETCL), which manages electricity transmission. It is a single operator of the transmission system and is owned by the government of Uganda.

   UETCL buys electricity in bulk from the generating companies and sells it in bulk to the distribution companies. It is also licensed to import and export electricity**.** The grid connects power generation plants to load centers throughout the country, as well as interconnection with neighboring countries. UETCL plays a role of a Transmission System Operator (TSO) hence conducting the system operations, which include the dispatch and control of the operation of generation plants and other facilities necessary for system stability, security, reliability, safety and efficient operations. UETCL coordinates the power supply system to obtain instantaneous balance between the generation and consumption of electricity. UETCL also manages transmission outages, monitor the import and export of electricity and prepare forecasts of capacity requirements. In addition, it is responsible for the grid expansion projects with the aim of upgrading and expanding the national grid. It expands and maintains the national grid both locally and through regional interconnections, to ensure availability of a wide grid to guarantee reliable electricity supply, to increase regional power trade, and to increase national coverage.

However, while increasing the size of national grid, UETCL has faced many challenges including; limited load (utilization) growth amidst the increasing generation capacity, a weak distribution infrastructure system/grid (not owned by UETCL) to evacuate power from embedded generators, and lack of harmonization of new Independent power producers (IPPs), and grid expansion. As mentioned earlier, limited access to electricity negatively impacts on the community. People end up resorting to other sources of energy, which leads to the depletion of the forests. Hence, increasing investment in electricity access and while reducing on the tariff could improve on the households' welfare through, health, saving time and environment. Moreover, with the help of elasticities, the utilities can manage better the demand side of electricity, which in turn would reduce peak demand hence reducing the heavy investment in expensive peak generation facilities.

2.1 Other Energy sources

The majority of Uganda's population depends on firewood or charcoal for domestic energy needs (Ojelel, 2015; Tabuti et al., 2003). Firewood is used for domestic cooking, as well as commercial activities such as making bricks, distilling spirits, preserving fish, cooking food in restaurants, and producing charcoal.

Generally, firewood has its shortcomings. It is difficult to ignite, burns out easily, and produces too much smoke and ash which is not good for human health.

The firewood for domestic use is collected mainly by women and children. Collecting firewood is time consuming. The distances travelled to collect firewood differs from area to area. In

Soroti where firewood supply is scarce (Egeru, 2014) people travel long distances, hence spend many hours looking for firewood.

On the other hand, firewood harvested for commercial use by small-scale industries requires large amounts of wood that is often green thus leading to the depletion of stock.

Charcoal as another fuel alternative, is the cheapest for cooking in urban areas of Uganda and its consumption is projected to rise as the urban population increases. However, Charcoal production has a negative effect on the environment, because it consumes large volumes of wood, produces emissions of volatile gases and is a major cause of tree felling resulting in greater loss of woodlands.

This heavy reliance on forests as a source of fuel especially due to increased charcoal production is not sustainable in the long run. It contributes to deforestation and local pollution as well as indoor pollution. Depletion of forests reduces both the economic welfare and growth since people find charcoal and firewood less costly than electricity.

Other energy sources used in the county include gasoline for vehicles and kerosene (paraffin) for lighting.

2.2 The Energy ladder And Energy stacking theories

While analyzing the income elasticity results, we shall follow the energy ladder theory which postulates that as income increases, households shift from traditional biomass and other solid fuels to more modern and efficient cooking fuels such as kerosene, LPG, and electricity. Therefore, the energy ladder has solid fuels, such as fuelwood and charcoal at the bottom, non-liquid fuels such as gas and oil in the middle, and electricity at the top (Leach, 1992). Although many empirical studies found evidence for the energy ladder (Behera et al., 2017), we do not know of its existence in Uganda where majority still use dirty fuels such as firewood, charcoal and kerosene as main sources of energy for cooking and lighting purposes.

On the other hand, researchers like (Masera et al., 2000; Ruiz-Mercado & Masera, 2015) have provided empirical evidence for the energy stacking hypothesis. According to this hypothesis, as a household's income rises, the household adopts modern fuels alongside the traditional ones. Therefore, the traditional fuels are not abandoned completely but rather are simultaneously used alongside the modern ones.

3 Methods and Data

3.1 Methods

In order to estimate demand elasticities, we assume a quasi-concave utility function of the sampled household and a choice behavior of each household to gain utility from any demand, given limited household income. We also assume that the amount of energy consumed by each household is a function of prices, household income and other economic factors. The prices of any of the four energy types of fuel affects the amount of quantities and the qualities the household can decide to consume (Deaton, 1990).

3.1.1 Separability

Assuming there are n goods, the unconditional demand function of good i, qi can be written a

$$q_i = f_i(p_1, p_2, \dots, p_n, y) \tag{1}$$

Where p_i is a price per unit of good i and y is the total expenditure.

We can allocate the total expenditure into two weakly separable groups: group A consisting of *k* energy goods and group B consisting of the rest of the goods (non-energy goods).

The expenditure for group A (y_A) is allocated between the energy fuel types. This gives the conditional demand functions as

$$q_i = g_i(p_{A1}, p_{A2}, \dots, p_{Ak}, y_A) \tag{2}$$

This further implies that any price change of any good in group B affects all energy types in group A in the same way. From the economic theory, we have identified some important variables to include in the model. They include income, price of electricity, and price of substitute energy sources.

3.1.2 Quadratic Almost Ideal Demand system (QUAIDS)

The concept of Quadratic Almost Ideal Demand System (QUAIDS) was developed by (Banks et al., 1997) and is an extension of the Almost Ideal Demand System (AIDS) model developed by (Deaton & Muellbauer, 1980). This type of demand system is more flexible than usual AIDS because it allows demand curves to be nonlinear in the logarithm of income and Engel curves.

Many researchers, including (Abdulai, 2002; Khanal et al., 2016), have applied the model. The QUAIDS model is generally derived from the usual indirect utility function:

$$\mathrm{lnV(p,y)} = \left(\left(\frac{\mathrm{lny} - \mathrm{lna(p)}}{\mathrm{b(p)}} \right)^{-1} + \lambda(\mathrm{p}) \right)^{-1} \quad (1)$$

where y is household expenditure on energy fuels, p are the prices, a(p) is the trans-log price aggregator expressed as

$$\mathrm{a(p)} = \alpha_0 + \sum_{j=1}^{n} \alpha_j \mathrm{lnp}_j + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \mathrm{lnp}_i \mathrm{lnp}_j \quad (2)$$

With $j = 1,2,3,4$ of energy fuel types, namely wood, kerosene, charcoal and electricity

$$b(p) = \beta_0 \prod_{j=1}^{n} p_j^{\beta_j} \quad (3)$$

where b(p) is a Cobb-Douglas aggregator and lastly the term $\lambda(\mathrm{p}) = \sum_{j=1}^{n} \lambda_j \mathrm{lnp}_j$ differentiable, homogenous function of degree zero of prices and where $\sum_{j=1}^{n} \lambda_j = 0$

By applying the Roy's identity to equation (3), we can derive the expenditure share of the QUAIDS model

$$\mathrm{S}_{jk} = \alpha_{jk} + \sum_{i=1}^{n} \gamma_{ij} \mathrm{lnp}_{ik} + \beta_j \ln\left[\frac{y_k}{\mathrm{a(p)}}\right] + \frac{\lambda_j}{\mathrm{b(p)}} \left[\ln\left(\frac{y_k}{\mathrm{a(p)}}\right)\right]^2 \text{ for } j = 1,2,3,4 \quad (4)$$

where S_{jk} is the budget share for each energy type of the k^{th} household in its total energy demand expenditures; $k = 1, ..., N$ denotes for the sampled households; p_{ik} represents the energy prices for the k^{th} household consumer; y_k represents the total energy expenditures of the k^{th} household; a(p) and b(p) are described above. α_{jk}, γ_{ij}, β_j and λ_j are the parameters to be estimated.

Excluding the quadratic term in equation (4), makes an AIDS model. Theoretically, the above equation must satisfy the laws of demand, which requires imposing the adding up condition, the homogeneity of degree zero property in prices and income, and the symmetry conditions of the Slutsky parameters, which results in the following restrictions of the QUAIDS model: $\sum_j \alpha_{jk} = 1$, $\sum_j \beta_j = 0$, $\sum_i \gamma_{ij} = 0$, $\sum_j \gamma_{ij} = 0$, $\sum_j \lambda_j = 0$ and $\gamma_{ij} = \gamma_{ji}$

3.1.3 Scaling

To account for heterogeneity among households, we include household demographic variables into the QUAIDS model. Specifically, the following demographic characteristics have been considered in our model: Age of household head, household size, marital status, education of the household head, as well as regional dummies. These demographics and household characteristics have been considered in the relevant literature (Heltberg, 2004; Khanal et al., 2016) and are found to significantly influence a household's purchase decisions.

Urban households have a strong preference for clean energy source given their poorer access to firewood and lack of space for lighting fires. We also expect the bandwagon effect to play role in influencing urban household to using electricity.

Household size has a positive impact on the gathering of wood for fuel, due to increased labor supply for firewood collection (Dewees, 1989; Heltberg et al., 2000; Nepal et al., 2011). Its impact on the probability of choosing clean cooking fuel is expected to be negative (Pandey & Chaubal, 2011). The education level of household members affects household energy choices by improving income. Educated people may have better-paying jobs, and therefore have a higher opportunity cost for their time doing household chores. They easily adopt to any time-saving device which in most cases require electricity. Education also directly increases knowledge and affects cultural and consumer preferences for cleaner energy sources. Therefore, we expect a positive relationship between education of household head and electricity (Gregory & Stern, 2014; Heltberg, 2004).

To assess the effect of household characteristics on energy demand we apply Ray (1983)'s technique:

$$e(p, z, \mu) = y_0(p, z, \mu) * e^R(p, \mu) \qquad (5)$$

Where z is a vector of s household characteristics, with the first term $y_0(p, z, \mu)$, scaling the expenditure function to control for household demographics characteristics and the last term $e^R(p, \mu)$ represents the expenditure function of a reference household[1]. The scaling function is further decomposed into two components;

$$y_0(p, z, \mu) = \bar{y}_0(z) * \phi(p, z, \mu) \qquad (6)$$

With the first term measuring the increase of household expenditure as a function of z, irrespective of the consumption patterns. For example, a household with three members will incur higher expenditures than one with one member.

The second term accounts for the changes in the relative prices of the type of energy consumed and the actual energy consumed which is subject to household composition. For example, a house with 2 adults and 3 infants will require different energy types than one with 5 adults.

Developing from Ray's view, Poi (2012) suggested a parameterized QUAIDS as

$$\bar{y}_0(z) = 1 + \rho' z \text{ and } \ln\phi(p, z, \mu) = \frac{\prod_{j=1}^{k} p_j^{\beta_j}\left(\prod_{j=1}^{k} p_j^{\eta_j' z} - 1\right)}{\frac{1}{\mu} - \sum_{j=1}^{k} \lambda_j \ln p_j}$$

[1] Reference household is one that contains a single adult

with ρ being a vector of parameters to be estimated and η_j represents the jth column of the s×k parameter matrix η. Therefore, incorporating demographics into the expenditure share equation 4, becomes:

$$S_{jk} = \alpha_{jk} + \sum_{i=1}^{n} \gamma_{ij} \ln p_{ik} + (\beta_j + \eta_j' z) \ln \left[\frac{y_k}{\bar{y}_0(z) a(p)}\right] + \frac{\lambda_j}{b(p) c(p,z)} \left[\ln\left(\frac{y_k}{\bar{y}_0(z) a(p)}\right)\right]^2 \quad (7)$$

for $j = 1,2,3,4$

Where $c(p,z) = \prod_{j=1}^{k} p_j^{\eta_j' z}$ and $\sum_j \eta_{rj} = 0$ for $r = 1, \dots, s$

Where s are the household characteristics making the *z* vector.

Once again if $\lambda_j = 0$ for all j then we have an AIDS model with demographics.

3.1.4 Censoring data

Some households do not use all energy types. This leads to corner solutions. Zero expenditure values could be due to non-preference, non-affordability, and non-availability, among others. Failure to account for these missing values in the estimation procedures could lead to biased estimates (Me-Nsope & Staatz, 2016; Park et al., 1996). To solve this problem, first, we consider a households that have the probability of access to electricity greater than 0.1, then we assume that household makes energy consumptions decisions in a two-stages, first choosing which fuels to use, and then the quantity to use of the chosen fuels:

$$d_{jk}^* = Z_{jk}' \theta_j + Y_{jk}' \psi_j + v_{jk} \quad (8)$$

$$d_{jk} = \begin{cases} 1 & \text{if} \quad d_{jk}^* > 0 \\ 0 & \text{if} \quad d_{jk}^* \leq 0 \end{cases} \quad (9)$$

$$S_{jk}^* = \widehat{\Phi} s_{jk} + \theta_{jk} \widehat{\phi} \quad (10)$$

$$S_{jk} = d_{jk} S_{jk}^* \quad (11)$$

with j and k being the fuel type consumed and household indices, respectively, while y and z are the vectors of the exogenous covariates, S_{jk}^* and d_{jk}^* are unobserved household budget shares and latent discrete choice decision variables, respectively; and finally S_{jk} and d_{jk} are the observed dependent variables for household fuel consumption and non-consumption counterparts. In this process, first stage, households decide on to purchase or not to purchase each of the fuel type and then decide how much to spend of each type in the second stage, conditional on a positive purchase decision from the first stage. We estimate the first stage using a probit model that describes the consumption selection decisions. The predicted estimates from the first stage are used to generate cumulative distribution function, $\widehat{\Phi}()$ (cdf) and probability density function $\widehat{\phi}()$ (pdf), that are required to estimate a second stage augmented QUAIDS in equation (10). We note that unlike in the conventional system specification without censoring, the deterministic components on the right hand side of equation (11) do not add up to unity across all equations of the system, and so the error terms in the estimation form do not add up to zero (Yen et al., 2002). As a result, the usual procedure of imposing the adding-up restriction on the system and dropping one equation is not valid. Therefore, with censoring, equation (7) is estimated correctly when using the entire set of n equations (Yen et al., 2002).

3.1.5 Elasticities

Following similar approach by (Poi, 2012), we use equations (7)-(11) to derive expenditures and price elasticities by differentiating equation (10) with respect to $\ln y_k$ and $\ln p_{jk}$. Thus, the uncompensated price elasticity of fuel i with respect to the price changes of fuel j is given as:

$$e_{ij}^{m} = -\delta_{ji} + \frac{1}{S_{jk}^{*}}\left(\Phi_j\left(\gamma_{ij} - \left[\beta_j + \eta' z + \frac{2\lambda_j}{b(p)c(p,z)}\ln\left[\frac{y_k}{\bar{y}_0(z)a(p)}\right]\right] * \left(\alpha_j + \sum_{n=1}^{N}\gamma_{jn}\ln p_n\right) - \frac{\left(\beta_j + \eta_j' z\right)\lambda_j}{b(p)c(p,z)}\left(\ln\left[\frac{y_k}{\bar{y}_0(z)a(p)}\right]\right)^2\right) + \theta_j\right) \quad (12)$$

where δ_{ji} is the Kronecker function with $\delta_{ji} = 1$ if $i = j$, and $\delta_{ji} = 0$ if $i \neq j$; Expenditure elasticity for good j is given as

$$\sigma_j = 1 + \frac{1}{S_{jk}^{*}}\left(\Phi_j\left[\beta_j + \eta' z + \frac{2\lambda_j}{b(p)c(p,z)}\ln\left[\frac{y_k}{\bar{y}_0(z)a(p)}\right]\right] + \theta_j\right) \quad (13)$$

Lastly, from expenditure and Marshallian price elasticities above, we can derive the compensated (Hicksian) price elasticities as

$$e_{ij}^{h} = e_{ij}^{m} + \eta_j S_{jk}^{*} \quad (14)$$

3.2 Data

We use the Uganda National Panel Survey 2013/2014 data. The data is a national representative household survey, and it has detailed information on topics that include; household characteristics, energy and non-energy expenditures, as well as other socio-economic characteristics. The sampled households were stratified into four regions (Central, Northern, Western and Eastern), districts and enumeration areas. We used expenditure data to proxy income, specifically the expenditure on fuel types following the separability assumption described above. In the cases where quantity consumed was not reported, it was calculated by dividing expenditure by the reported unit price. Electricity price was not available in the survey, so the unit price was extracted from the website of the Electricity Regulatory Authority as reported by each distributor in their respective supply regions. Kerosene price was reported in of a variety of consumption units including; bottles, tins, cups and bottle tops. These were standardized into cost per liter and number of liters consumed. Firewood too had a variety of measurements, which we converted into bundles consumed and cost per bundle.

Similarly, the survey reported units of consumption of charcoal in terms of bags of different sizes with unspecified weight, tins of different sizes, and heaps. We also standardized these into one measurement unit (kilograms) and the cost per kilogram.

The unit prices of charcoal, firewood and kerosene may induce measurement errors since households had different measurements and no proper conversion ratios were provided. This could lead to biased estimates. However, these measurement error of unit values are minimized by using household characteristics (control variables) which include, household size, and education of household head among others. In addition, (Cox & Wohlgenant, 1986) suggested that, households located in the same region face the same prices and as a result urban dummy variable is included in the regressions.

For zero-consuming households, imputed prices based on the average fuel price for their enumeration area were assigned.

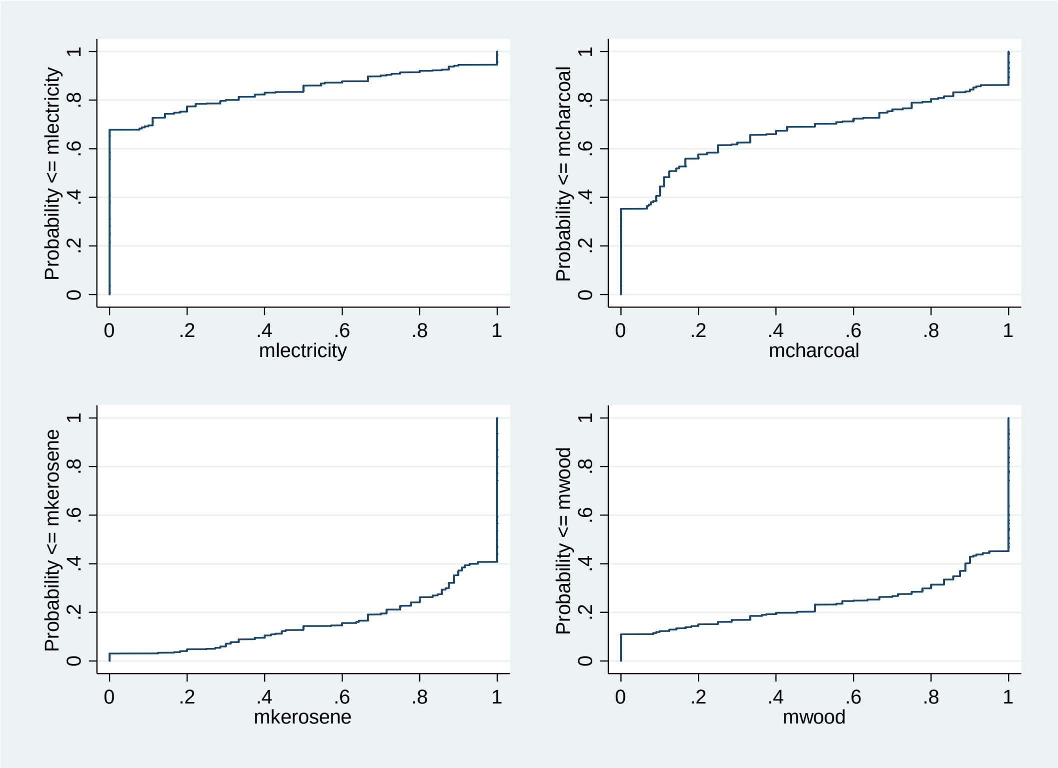
For all energy types, the constructed energy expenditure shares were used as the dependent variables and the independent variables included: the logs of per unit prices of the energy types, income, income squared, and household control variables including; dummy for urban, household size, age of household head, dummy for marriage, education level of the household head and a dummy for the sex of the household head. Estimates for energy shares were obtained by QUAIDS model with the consideration of non-consuming households of an energy type. There are a few households with access to electricity with most of them living in the urban. It is not possible to determine if the household does not consume electricity by choice, or by exclusion since the survey did not include information on the availability of electricity networks in the area. Therefore, in our study, we decided to consider only enumeration areas with a probability of access greater than 0.1. We also included all household connected to the national grid even when they belonged to enumeration areas with less than o.1 probability. The probability of access of an enumeration area was constructed by dividing the number of households connected to the grid, by the total number of households in that enumeration area

After data cleaning we have 687 households used in the analysis. Households were primarily eliminated due to the lack of basic information on household energy expenditure or lacked access to electricity.

4 Descriptive Statistics, and Results' interpretation

4.1 Descriptive statistics

Graph 1: cumulative distribution function for Electricity, Charcoal, Kerosene, and wood respectively



The graph shows the proportion of households that use a certain energy fuel per enumeration area

Focusing of electricity, we notice that about 63% of the enumeration areas do not use electricity hence need for data censoring

The following tables show the descriptive statistics for

Table 1: Expenditure on different energy sources, as a share of total energy expenditure

Variable	Mean	Standard Deviation
Firewood	0.07	0.2
Kerosene	0.27	0.38
Charcoal	0.43	0.38
Electricity	0.23	0.31

Table 2: Descriptive statistics

Variable	Mean	Std.dev	minimum	maximum

Household Energy Expenditure (UGX)	38609	38656.3	500	348032
Price of Electricity (UGX/ KWh)	529	19.16	509	570
Price of wood (UGX/)	847	515.32	250	2500
Price of charcoal	859	389.4	80	3333
Price of kerosene	1979	851.76	200	3500
Household size	5.29	3.04	1	23
Education level	8.06	5.27	0	16

Table 3: Description statistics for included binary variables

Variable		percent
Urban/rural Identifier	Urban	76
Marriage Identifier	married	66
Dummy for wood usage	use wood	14
Dummy for kerosene usage	use kerosene	61
Dummy for charcoal usage	use charcoal	67
Dummy for electricity usage	use electricity	44

4.2 Results' analysis and discussion

We estimate the expenditure and price elasticities using the Quadratic Almost Ideal demand system (Banks et al., 1997). Due to censored expenditure observations for each energy group item, we estimate the QUAIDS[2] model, augmented with the cumulative and probability density functions obtained from the probit model described earlier to minimize selection problems. We also consider both household and demographic variables that might influence consumer preferences. In doing so, we used household location, urban indicator variables to capture demographic influences on household consumption decisions. Other socio-economic variables such as gender of household head, size of household, marital status of household head and age of household head, are included to account for household characteristics in purchase decision.

Table 4: Results from the first stage probit model

	Firewood	Kerosene	Charcoal	Electricity
Household-size	0.67	-0.03	-0.1	0.06
urban	-0.1	-0.95	0.96	0.72
education	-0.01	-0.03	0.02	0.05
age	-0.06	0.01	-0.02	-0.02
Marriage	0.62	0.04	0.16	0.06
rooms	0.08	-0.1	-0.18	0.26
gender	-0.32	-0.08	-0.4	0.02

[2] The full estimated parameters of QUAIDS model are reported in Appendix 3.

The results show that living in urban increases the probability of using electricity. Increased level of education also increases the probability of using electricity while reducing that of using firewood.

Table 5: QUAIDS results of control variables

VARIABLE	Cofficient	Standard error
Firewood- household-size	0.040***	(0.004)
Firewood - education-level	-0.004*	(0.002)
Firewood - urban	-0.155***	(0.029)
Firewood -marriage	0.304***	(0.035)
kerosene- household-size	-0.009***	(0.001)
kerosene - education-level	-0.003***	(0.001)
kerosene - urban	-0.285***	(0.014)
kerosene -marriage	-0.049***	(0.008)
charcoal- household-size	-0.006***	(0.001)
charcoal - education-level	-0.002*	(0.001)
charcoal - urban	0.363***	(0.018)
charcoal -marriage	0.042***	(0.008)
electricity- household-size	-0.001	(0.002)
electricity - education-level	0.001	(0.001)
electricity - urban	0.097***	(0.021)
electricity - marriage	-0.051***	(0.011)

The estimated parameters of QUAIDS models are reported in the table 5 above. The table shows that all the parameters of the household demographic attributes exhibit statistically significant values, which shows that household energy demand depend on household characteristics. we also observe that the higher the level of education the higher the probability of using electricity. Education negatively affects the demand of firewood, kerosene and charcoal. Therefore, policies that encourage more education will help reduce the usage of non-renewable and unclean energy types.

4.3 Expenditure elasticities

Table 6: Expenditure elasticities

Firewood	Kerosene	Charcoal	Electricity
0.714	0.936	1.24	0.742
(0.11)	(0.05)	(0.07)	(0.10)

In parenthesis are the corresponding standard errors of the parameters

The expenditure elasticities obtained from the estimated QUAIDS model, are reported in Table 4 above. The estimates from each energy type are statistically significant at 1% level. Only charcoal has an expenditure elasticity greater than one. This is an indication that households spend proportionally more on it as income increases. Therefore, it is a luxury good. The high-income elasticity of charcoal further indicates the households' resistance to move from charcoal to cleaner fuels such as electricity.

Households may prefer charcoal for cooking even when their incomes have improved enough, while they use electricity for lighting. This is evidence for "fuel stacking". According to the 'Fuel-Stacking' hypothesis, when income increases, households do not fully switch to different fuel types, but rather use an energy mix. The households rely on multiple fuels to meet their energy-demands. For instance, many households use charcoal for cooking and electricity for lighting purposes.

Most households find charcoal superior to firewood and so when their incomes increase, they switch from firewood to charcoal hence supporting the energy ladder only up to this level (though as a solid fuel, charcoal is still in the bottom part of the energy ladder). They then turn to fuel stacking. The remaining three fuel types' expenditure is inelastic. Hence, although, they are normal goods. Income changes do not change much of their demand.

We conduct a statistical test to find out if the expenditure elasticity for each energy type is significantly different from one. We reject the null hypothesis that the expenditure elasticity is equal to one for energy fuels except Kerosene. We note that all the estimated expenditure elasticities are conditional in the way that they represent the response of households to changes in total energy expenditures.

4.4 Price elasticities

All Marshallian and Hicksian price elasticity estimates are computed at sample mean and reported in Table 5 below.

Table 7: ***Marshallian(uncompensated) Price elasticities and Hicksian (compensated) Price elasticities***

	Marshallian Price elasticities				**Hicksian Price elasticities**			
	wood	**kerosene**	**Charcoal**	**Electricity**	**Wood**	**kerosene**	**Charcoal**	**Electricity**
Wood	**-1.26**	0.29	-0.02	0.09	**-3.01**	1.88	-0.65	0.37
	(0.09)	(0.10)	(0.05)	(0.04)	**(0.68)**	(0.51)	(0.35)	(0.25)
Kerosene	-0.02	**-0.96**	-0.03	0.07	0.02	**-0.69**	0.34	0.32
	(0.04)	**(0.05)**	(0.02)	(0.04)	(0.07)	**(0.06)**	(0.07)	(0.05)
Charcoal	0.17	-0.22	**-0.95**	-0.15	0.34	0.04	**-0.34**	0.1
	(0.06)	(0.07)	**(0.03)**	(0.06)	(0.10)	(0.08)	**(0.08)**	(0.07)
Electricity	-0.27	0.27	-0.09	**-0.88**	-0.58	0.72	-0.01	**-0.62**
	(0.11)	(0.10)	(0.05)	**(0.11)**	(0.27)	(0.17)	(0.19)	**(0.21)**

The figures in parenthesis are the standard deviations. The bold numbers are own-price elasticities.

All own-price elasticities for energy types showed in tables 5 above are negative. This implies that the negativity condition is fulfilled hence consistent with economic theory. We also observe that, compared to uncompensated elasticities, some of the Hicksian cross-price elasticities have different signs which implies that, household income effects play a significant role on energy demand. From theory, a negative cross-price elasticity implies that the two energy fuels are complements while, a positive cross-price elasticity indicates that the energy types are substitutes.

4.4.1 **Marshallian (uncompensated)**

First, we analyze the Marshallian price elasticities since they are what we observe. Results show that the own price elasticities of energy types range between -1.26 and -0.876.

Cross elasticities indicate that wood complements kerosene and electricity. Hence, as firewood is used for cooking, electricity and kerosene are used for lighting purposes. The results also show that firewood is a substitute to charcoal. The two biofuels are commonly used for cooking, and so the results are in line with what we commonly observe in the country.

Results indicate that kerosene is a substitute to firewood. This is because kerosene is also used for cooking purposes in some areas. The results also indicate that kerosene is a substitute to electricity. We observe that both fuels are used for lighting. Kerosene is a complement to charcoal and the two types of fuels serve different main purposes.

Charcoal is a compliment to all fuel types. Charcoal is mainly and almost exclusively used for cooking hence complimenting electricity, and kerosene which are mainly used for lighting. It also complements firewood, especially during those seasons when firewood cannot be collected due to heavy rainfall, and other factors like sickness of the one who collects it in a household.

The Marshallian results indicate that, electricity substitutes wood and kerosene, while complementing charcoal for similar reasons mentioned above. Many households are reluctant to switch to electricity for cooking purposes because of their cooking habits, cultures, and preferences. For example, when cooking a traditional food called “matooke” one must leave it on fire for a whole day. Besides, there are other underlying heavy costs of buying a cooker and other appliance required in the cooking while using electricity.

4.4.2 Hicksian (compensated) demand

The Hicksian price elasticities reported in table 5 and can be used to reflect substitution effects in the elasticities. Considering the Hicksian results we find that Electricity has an own price elasticity of -0.623 which indicates it has inelastic demand hence it does not significantly respond much to price changes although in the long run its response can be seen in changes of the appliances used by the household. In Uganda, we observe that once a household is connected to the grid, small price changes have little effect on changes in demand of electricity. Even the small noticed changes are seen through the changes in the demand of electricity appliances.

The results also show that electricity is a substitute with each of the other energy fuels since the cross elasticities are all positive. The cross elasticity between electricity and charcoal is the smallest, indicating that people are rigid to change from charcoal to electricity even when the electricity price is low.

The correlation between electricity consumption and other fuel types suggests that changing the price of electricity will influence shifting household's energy mix itself.

Firewood has a price elasticity of -3 which implies that a 1% increase in its price will lead to a 3% reduction in its quantity demanded by a household that uses it. While firewood is a compliment to electricity, it is a substitute to charcoal and kerosene consumption. Therefore, we note that firewood is a compliment to electricity while electricity is substitute to firewood. This shows that even if the firewood price was so low, firewood wood would still not substitute electricity to run the electric appliances but would rather compliment with the cooking purposes. Therefore, overall results suggest that manipulating firewood price will affect the household energy mix towards Electricity.

Kerosene is a substitute to all the other fuel types. Kerosene is mainly used for lighting and so it substitutes electricity in that purpose. It is also used in the small cooking stoves for cooking thus substituting firewood and charcoal in that purpose. Therefore, tampering with the price of kerosene influences the demand of charcoal, firewood and electricity.

Charcoal is a compliment to wood and electricity while it is a substitute to kerosene. A one percent increase in the price of charcoal only reduces the demand for electricity by 0.013 %.

Although the responsiveness is small, it reflects the rigidity of the household to change from charcoal consumption to clean energy fuels.

All the other control variables[3] are significant at 5% level in all fuel types. These variables hence indicate that it is quite difficult to use only a single energy type. For example, household of larger size will depend on charcoal and electricity.

Generally, we can say that for policy purposes with the aim of increasing the consumption of clean energy and less of charcoal and firewood, the government can use tax incentives since electricity is their substitute, but should also increase the households income since the income substitution effect is seen. The government should also address the transmission constraints of electricity by expanding the grid to ensure reliability.

5 Conclusion and policy relevancy

The study aimed at exploring ways of increasing the demand and usage of electricity in Uganda hence improving people's welfare. Electricity is a clean renewable energy, and its installed capacity is greater than its current demand in the country. Low usage of electricity negatively impacts on the community and leads to the depletion of forests. In this paper, we analyzed the household demand for energy types using an augmented QUAIDs model that corrects for censored distribution of expenditure shares. The findings show that increasing education levels, income, and living in urban areas increases the demand of electricity.

The uncompensated own price elasticities are very close to unit. Generally the results are not in line with (Halvorsen, 1975) who found that long-run own-price elasticity of demand was equal to at least unity except for firewood.

The results further indicate that, expenditure elasticity estimates for each energy type are statistically significant at 1% level. Increasing households' income can help achieving the objective of increased demand of electricity since the income and substitution effects are observed through the differences between Marshallian and Hicksian own-price elasticities. Notably, the government should also address the transmission constraints of electricity by expanding the grid to ensure reliability.

[3] Reported in appendix

Through analyzing the income elasticities, we observe that the household energy use in Uganda does not conforms to the energy ladder theory. As households' incomes increase, they switch from firewood use too charcoal consumption, and there after use a mix of energy fuels. Therefore, the results indicate that majority of the households in Uganda use a mix of energy fuels even when their incomes are high, hence supporting the energy stacking theory. However, we also observe that as households' income increase, households consume some clean fuels like electricity.

Electricity consumption shows a direct relationship with income and this is true for all other energy fuels. To be specific, our results indicate that as household income increase, the usage of firewood and charcoal increases too. This may indicate the lack of cheap energy alternatives.

6 Recommendation

The government can intervene with different incentives to increase the consumption of Electricity. They include expanding the transmission lines, reducing or freely connecting new consumers and constantly monitoring the distributors regulated by ERA over their prices and costs. The government should also encourage households to use solar electricity since it is relatively cheaper to connect.

On the other hand, given that electricity prices cannot be reduced directly since the investors in the generation companies expect a return above costs to cover all risks, we recommend that the government can target income, education and other significant variables to achieve the aim of increasing the consumption of Electricity

The QUAIDS results showed that electricity is a substitute of all the other fuel types, therefore we would recommend that the government reduces electricity price through subsidies. However, subsidy is an expensive incentive especially for a developing country like Uganda. Therefore, taxing unsustainable energy sources like charcoal and wood could be appropriate since the two would become expensive making electricity relatively cheaper. However, taxes will reduce the standard of living for the poor. Besides, it is difficult to implement. Therefore, this policy recommendation requires further study.

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Conflicts of interest:
We declare no conflict of interest.

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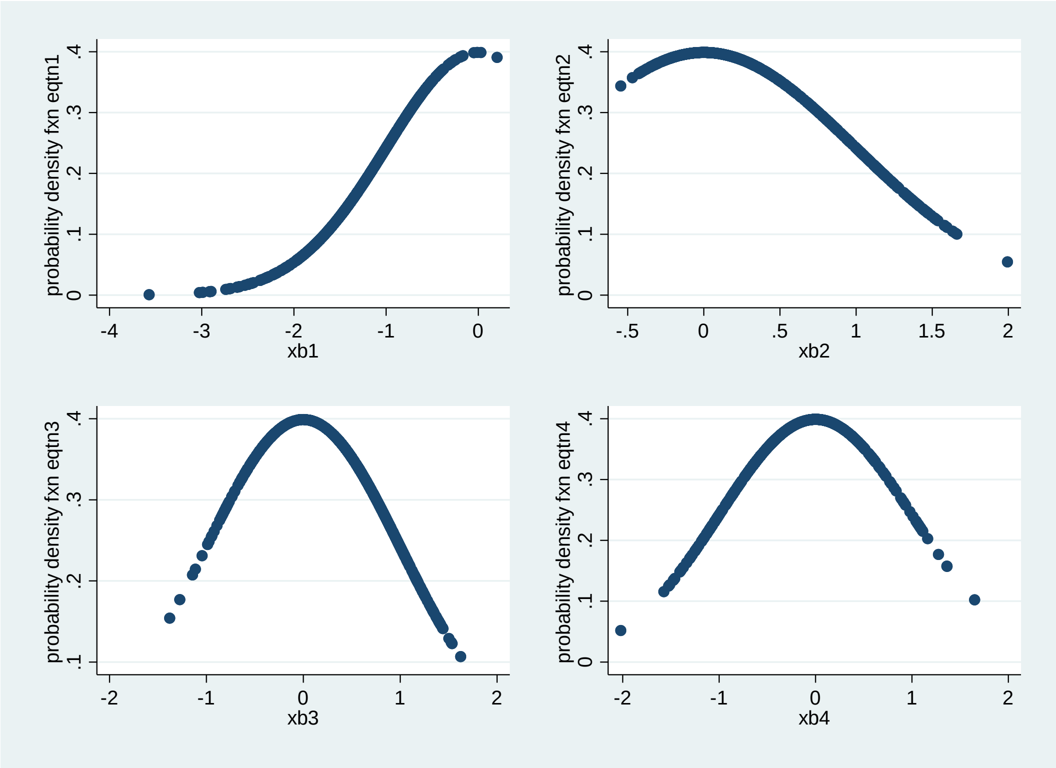
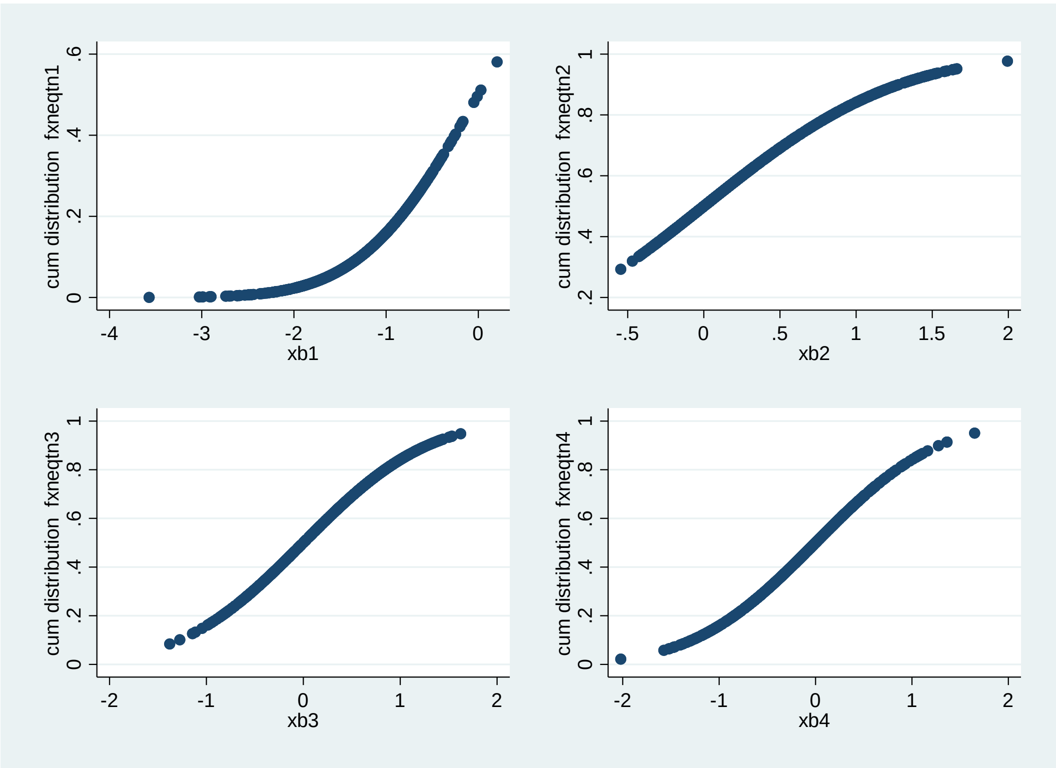
8 Appendix

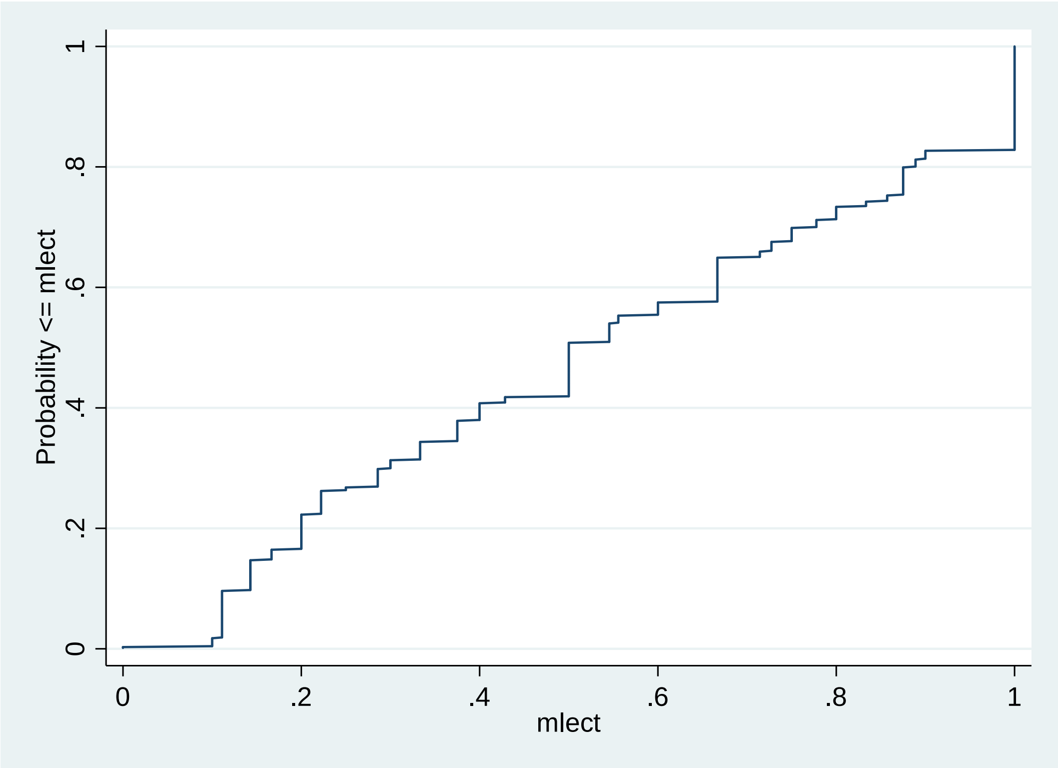
Appendix 2: Probability density functions for wood, Kerosene, Charcoal and Electricity respectively



Appendix 3: Cumulative distribution functions for wood, Kerosene, Charcoal and Electricity respectively



Appendix 3: Cumulative distribution functions for wood, Kerosene, Charcoal and Electricity respectively



Appendix 4: Expenditure share QUAIDS regression results.

coefficients	Constant	standard errors
a1	-0.520***	(0.158)
a2	0.949***	(0.056)
a3	-0.207*	(0.113)
a4	0.571**	(0.224)
b1	-0.053*	(0.029)
b2	-0.020*	(0.010)
b3	0.075***	(0.022)
b4	-0.065***	(0.025)
g11	-0.038	(0.025)
g12	0.008	(0.007)
g13	0.020*	(0.010)
g14	-0.025**	(0.012)
g22	-0.009**	(0.004)
g23	-0.005	(0.005)
g24	0.010	(0.007)
g33	-0.002	(0.011)

g34	-0.000	(0.013)
g44	-0.006	(0.041)
lam1	0.006***	(0.002)
lam2	0.001	(0.001)
lam3	-0.005***	(0.002)
lam4	0.005***	(0.002)
r11	0.040***	(0.004)
r12	-0.004*	(0.002)
r13	-0.155***	(0.029)
r14	0.304***	(0.035)
r21	-0.009***	(0.001)
r22	-0.003***	(0.001)
r23	-0.285***	(0.014)
r24	-0.049***	(0.008)
r31	-0.006***	(0.001)
r32	-0.002*	(0.001)
r33	0.363***	(0.018)
r34	0.042***	(0.008)
r41	-0.001	(0.002)
r42	0.001	(0.001)
r43	0.097***	(0.021)
r44	-0.051***	(0.011)
d1	0.180***	(0.049)
d2	0.285***	(0.034)
d3	0.435***	(0.017)
d4	0.117***	(0.027)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: 1=wood, 2=kerosene 3=charcoal 4=electricity

Note: r11=household-size for wood equation, r12= education-level for wood equation, r13 =urban for wood equation, r14= married for wood equation. The next are for kerosene, charcoal and electricity respectively

The estimated parameters of QUAIDS models are reported in the Appendix above. The table provides estimated parameters on log of price of each energy type, log household income estimates, and its quadratic form, as well as set of household demographics. The table also shows that all the parameters of the household demographic attributes exhibit statistically significant values, which shows that household energy demand depend on household characteristics. The coefficients of log of income and log of income squared of fuel types are also significant. In the short and medium term, income growth leads to an increased consumption of charcoal which is not the case in the remaining three fuel types. Most parameter values from censored observations are statistically significant at 1% in each energy group except for wood hence it is importance to adjust for zero household expenditure in observations. From these results, we also observe that the higher the level of education the higher the probability of using electricity. Therefore, policies that encourage more education will help reduce the usage of non-renewable and unclean energy types.

Appendix 5: first stage regression

Averaged Beta-Hat Point Estimates and Estimated Standard Errors

	y1	y2	y3	y4
lnagehhd	3.377	.2757	.4542	.3251
	(1.3039)	(.7806)	(.8239)	(.7664)
lnhhsize	-.2522	.1667	.5945	-.2345
	(.2783)	(.2124)	(.2216)	(.206)
urban	-.104	-.9502	.9631	.7226
	(.1463)	(.1389)	(.12)	(.1325)
age_hhd	-.0584	.0069	-.0198	-.0151
	(.0265)	(.0175)	(.018)	(.0172)
hhsize	.0697	-.0294	-.1014	.0581
	(.0521)	(.0434)	(.0448)	(.0426)
gender	-.3118	-.083	-.42	.028
	(.1623)	(.1328)	(.1551)	(.1289)
educ_level	-.005	-.0264	.0245	.0474
	(.0131)	(.0102)	(.0107)	(.0103)
married	.6212	.0413	.1603	.0612
	(.1862)	(.1436)	(.1581)	(.1366)
room_no	.0882	-.0961	-.1801	.2634
	(.0588)	(.0524)	(.0512)	(.0541)
_cons	-11.5294	.1041	-1.016	-2.2693
	(3.6922)	(2.1225)	(2.2553)	(2.0769)

Notes: y1 "dummy for wood usage" y2 "dummy for kerosene usage" y3 "dummy for charcoal usage" and y4 "dummy for electricity usage"