Household Energy Consumption and Its Determinants in Timor-Leste

DIL BAHADUR RAHUT, KHONDOKER ABDUL MOTTALEB, AND AKHTER ALI*

Using data from the 2007 Timor-Leste Living Standards Survey, this paper examines the determinants of household energy choices in Timor-Leste. The majority of households are dependent on dirty fuels such as fuelwood and kerosene for energy. Only a small fraction of households use clean energy such as electricity. Econometric results show that wealthy households, urban households, and those headed by individuals with higher levels of education are less likely to use and depend on kerosene and more likely to use and depend on electricity. While female-headed households are generally more likely to use and depend on fuelwood, richer female-headed households are more likely to use and depend on electricity. Our findings highlight the importance of ensuring an adequate supply of clean energy for all at affordable prices and of investing in education to raise awareness about the adverse impacts of using dirty fuels.

Keywords: education, energy, fuelwood, household, income, Timor-Leste
JEL codes: D12, I25, I31, Q42

I. Introduction

More than 1.4 billion people worldwide lack access to clean energy such as electricity, while 2.7 billion people rely on dirty energy such as biomass and fuelwood for cooking (Kaygusuz 2012).[1] Enhancing access to clean energy is a prerequisite for sustainable economic development (Spalding-Fecher 2005, Abebaw 2007). Alarmingly, a lack of access to clean energy is found to be associated with ill health and the prevalence of poverty (Ekholm et al. 2010). Unfortunately, the majority of households, particularly in rural areas in developing economies, lack access to clean energy sources such as electricity even though demand for clean energy consistently increases in line with rising household incomes in these economies.

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[1]As electricity and gas pollute the atmosphere less than coal, kerosene, and fuelwood, the former are referred to as "clean energy," while the later are referred to as "dirty energy."

Inadequate supply, the consequent high costs, and a lack of purchasing power are the major barriers to a household's conversion to clean energy sources in developing economies (Arntzen and Kgathi 1984; Heltberg, Arndt, and Sekhar 2000). The price of energy increases with improvements in energy quality and its ease of use (Behera et al. 2015, Rahut et al. 2014).[2] For example, fuel costs increase as a household shifts from solid fuels such as biomass to other fuels such as gas and electricity. The energy ladder hypothesis postulates that with increases in income and awareness, households gradually shift from solid fuels to more modern and efficient energy sources such as liquid petroleum gas, natural gas, and electricity (Leach 1975, 1992). Several studies have documented that the energy sources used by households change as income levels increase (Rao and Reddy 2007; Khandker, Barnes, and Samad 2012; Rahut, Behera, and Ali 2016), with a shift from traditional to modern fuels (Daioglou, Van Ruijven, and Van Vuuren 2012), particularly electricity (Hills 1994). A few studies, however, have found that increased incomes do not always lead to households switching to cleaner fuels (Masera, Saatkamp, and Kammen 2000; Nansaior et al. 2011; Huang 2015). Thus, the direction of the relationship between income and the demand for clean energy remains uncertain and thus requires further investigation using large samples across economies (Khandker, Barnes, and Samad 2012).

Using data from the 2007 Timor-Leste Survey of Living Standards (TLSLS), this paper analyzes the influences of income and human capital on household energy choices in developing economies. Understanding patterns of household energy consumption and the determinants of energy choices is important. Timor-Leste, a newly independent small country in Southeast Asia with an area of 15,410 square kilometers and a population of 1.2 million, is one of the poorest economies in the world with a poverty rate of 27% (Datt et al. 2008). It was a Portuguese colony for 450 years and later governed by Indonesia from 1976 to 2002. On 20 May 2002, Timor-Leste became a sovereign state, joining the United Nations and the Community of Portuguese Language Countries.

Since independence, Timor-Leste has aspired to boost the provision of electricity through a grid extension program based on the national rural electrification master plan (Government of Timor-Leste 2012). In 2002, only 36% of Timor-Leste's 0.825 million people had access to electricity, most of whom were concentrated in the capital of Dili (International Monetary Fund 2004). In its most recent survey, the World Bank found that access to electricity was limited to 6%–10% of rural households (World Bank 2005). The nearly two-thirds of all households in Timor-Leste that lack access to electricity mainly depend on kerosene and candles to meet their lighting needs. Fuelwood is the cheapest form of fuel available and

[2]In this paper, the quality of an energy source is defined in terms of the nature of its pollution. Sources of energy that emit smoke and pollute the environment like fuelwood, dung cake, coal, and kerosene are regarded as low quality sources of energy. Sources like liquid petroleum gas and electricity are regarded as high quality.

is used by 95% of households in Timor-Leste for cooking (World Bank 2005). This heavy reliance on fuelwood is the main cause of rapid deforestation in Timor-Leste. In addition, the indoor air pollution generated using fuelwood is a major concern for human health. In 2003, total health expenditure from indoor air pollution was estimated at $12.4 million, or 1.4% of gross national income (Arcenas et al. 2010).

Households in Timor-Leste spend an average of $14.3 on energy per month, which is the equivalent of 20% of a typical rural household's monthly income and on average, members of a household spend 3.5 hours per day for cooking and allocate 6 hours per week for collecting fuelwood (Mercy Corps 2011). An average household uses 9.3 kilograms of fuelwood daily and 3 tons annually (Mercy Corps 2011). In addition to being the primary source of deforestation, this massive use of fuelwood negatively affects the agricultural systems of Timor-Leste (World Bank 2010).

Timor-Leste has vast reserves of natural gas in the Timor Sea and thus has great potential for generating electricity cheaply (Strategic Development Plan 2011). Against this backdrop, an analysis of household energy choices in a newly independent and poverty-stricken developing economy can provide guidance to policy makers and international donors on what types of energy should be promoted for facilitating rapid economic development and reducing widespread poverty.

This paper makes four distinct contributions to the existing literature. To the best of our knowledge, no such energy study has been carried out in Timor-Leste using large, nationally representative household data sets. Thus, this study can provide insight to policy makers and donor agencies on domestic energy policy in Timor-Leste. Second, the study confirms the existing energy ladder hypothesis, which suggests there is (i) an inverse relationship between household wealth and education levels and the use of traditional energy such as biomass, and (ii) a positive relationship between household wealth and education levels and the use of clean energy such as electricity. Third, this paper is unique in using econometric models, including a multivariate probit model to analyze the factors influencing household energy choices and a Tobit model to examine the intensity of energy consumption based on the share of household expenditure allocated for different energy sources. Finally, we reestimate our econometric models by splitting and employing the sampled observations into 75%, 50%, and 25% segments to examine the robustness and sensitivity of the findings.

The paper is organized as follows. Section II includes a brief literature review and two testable hypotheses. Section III outlines the data sources and data collection process, as well as the specification of econometric models. We subsequently present descriptive analyses, empirical results, and discussions of the determinants of household energy choices in section IV. Section V presents consumption intensity. Section VI presents major empirical findings. Section VII concludes with a discussion of the policy implications.

II. Literature Review and Testable Hypotheses

The energy ladder hypothesis postulates that as incomes rise households gradually shift from solid fuels to more modern and efficient energy sources such as kerosene, liquid petroleum gas, natural gas, and electricity (Leach 1975, 1992). Thus, the transition from solid fuels to more efficient and modern energy sources is greatly influenced by household income (Hills 1994; Rao and Reddy 2007; Daioglou, Van Ruijven, and Van Vuuren 2012; Khandker, Barnes, and Samad 2012). With an increase in income, the opportunity cost of collecting fuelwood increases. In many cases, it might be more efficient for high-income households to switch to natural gas, kerosene, or electricity as a source of fuel rather than collecting fuelwood given the rising opportunity cost involved. A few studies, however, failed to establish any correlation between rising incomes and households switching to efficient energy (Masera, Saatkamp, and Kammen 2000; Nansaior et al. 2011). To understand the direction of the relationship between income and energy choices as incomes rise, we postulate the following hypothesis:

Hypothesis (1): It is highly likely that households with relatively higher incomes are less likely to depend on kerosene and fuelwood and more likely to choose electricity and other efficient fuels. Thus, they will spend relatively more income on clean energy such as electricity.

Household demographics such as the sex of a household head can have a significant influence on energy choices as female members have a strong preference for using cleaner and more convenient energy sources. In developing economies, female household members are generally responsible for collecting fuelwood and cooking (Farhar 1998). For example, in India, females are more involved in collecting fuelwood from forests than their male counterparts (Heltberg, Arndt, and Sekhar 2000). Thus, female household members play an active role in energy use from collecting fuel to making decisions on fuel sources (Reddy and Srinivas 2009). Use of clean energy has a positive impact on the health and well-being of households, particularly children and female members. Hence, when a female member is the principal decision-making agent (household head), higher priority will be given to the use of clean energy (Parikh 1995; Rahut, Behera, and Ali 2016), which is why empirical evidence strongly suggests that per capita fuelwood consumption in female-headed households is less than in male-headed households (Israel 2002). The age of the household head and family size can also play important roles in energy choices. While households with more family members need more energy, such households are also able to supply more labor for fuelwood collection and other activities in rural areas (Dewees 1989; Heltberg, Arndt, and Sekhar 2000; Nepal, Nepal, and Grimsrud 2011). Empirical evidence indicates an inverse relationship between family size and the use of clean fuel (Pandey and Chaubal 2011).

In addition to income and household demographics, the level of education of the household head, which can serve as a proxy for the level of human capital at the household level, can also affect household energy choices through enhanced nonfarm income and thus the affordability of more efficient energy sources, the increased opportunity cost of the time required for fuelwood collection, and raised awareness of the harmful effects of dirty fuel on the environment and health (Leach 1975, 1992). It is well documented that the use of solid fuels is detrimental to the environment and health (Bruce, Perez-Padilla, and Albalak 2000; Holdren et al. 2000; Rehfuess, Mehta, and Prüss-Üstün 2006). Empirical evidence confirms that education is a strong determinant of switching from traditional solid fuels to more efficient modern fuels (Heltberg 2005, Pachauri and Jiang 2008). To examine the relationship between choice of energy sources and household demographics and human capital, the following hypothesis is formulated:

Hypothesis (2): While households with more family members are more likely to depend on fuelwood and electricity for energy and therefore spend a relatively larger share of total energy expenditure on these sources, relatively more educated household heads are less likely to choose kerosene and therefore spend relatively less on it and more likely to choose clean energy such as electricity and therefore spend relatively more on it.

Generally, the focus of energy policy is to create incentives and enable households in developing economies to switch from traditional fuels such as biomass and fuelwood to clean energy such as electricity. By examining our testable hypotheses, this paper investigates household patterns of energy consumption and analyzes the factors that influence household energy choices in developing economies by using data collected under the TLSLS 2007 from more than 4,000 rural and urban households in Timor-Leste.

III. Data and Methodology

A. Data and Sampling

This paper uses data from the TLSLS 2007 to analyze household-level energy consumption and its determinants. The TLSLS is a government-administered activity with financial, intellectual, and technical support from the multidonor Planning and Financial Management Capacity Building Program managed by the World Bank.[3] The TLSLS is a comprehensive multimodule survey encompassing broad topics. Samples were selected in two stages. In the first stage, 300 census

[3]Meta data and detailed documentation can be found at http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTLSMS/0,,contentMDK:22764522~pagePK:64168445~piPK:64168309~theSitePK:3358997,00.html

Table 1. **TLSLS Distribution of Enumeration Areas and Full Sample by Region and Household Rural–Urban Status**

	Number of Enumeration Areas			Sampled Households		
Regions	**Rural**	**Urban**	**Total**	**Rural**	**Urban**	**Total**
1 (Baucau, Lautem, and Viqueque)	35	25	60	524	375	899
2 (Ainaro, Manufahi, and Manatuto)	35	25	60	517	374	891
3 (Aileu, Dili, and Ermera)	35	37	72	522	552	1,074
4 (Bobonaro, Cova Lima, and Liquica)	35	25	60	520	375	895
5 (Oecussi)	28	20	48	419	229	648
Total	**168**	**132**	**300**	**2,502**	**1,905**	**4,407**

TLSLS = Timor-Leste Survey of Living Standards.
Source: Government of Timor-Leste, Ministry of Finance. "Timor-Leste Survey of Living Standards 2007." http://www.statistics.gov.tl/wp-content/uploads/2013/12/Timor-Leste-Survey-of-Living-Standards-2007.pdf

Enumeration Areas were selected as the primary sampling units; in the second stage, 15 households were selected from each Enumeration Area. The first sampling stage used the list of 1,163 Enumeration Areas generated by the 2004 census as a sampling frame. Within each stratum, the allocated number of Enumeration Areas was selected with probability proportional to size, using the number of households reported by the census as a measure of size. The second sampling stage used an exhaustive household listing operation in all selected Enumeration Areas as its sampling frame. Sampled households in each Enumeration Area were selected from the list by systematic equal probability sampling. Table 1 shows the TLSLS distribution of the Enumeration Areas and full sample by region and by household rural–urban status.

B. Methodology

Generally, households depend on energy from multiple sources. Therefore, the choices to use a variety of individual energy sources are correlated with each other. To capture the mutually inclusive behavior of household energy choices, a multivariate probit model was employed to analyze the determinants of a household's energy choices. To test hypothesis 1 and hypothesis 2, we randomly split the total sample into four equal groups. While we first ran the multivariate probit model using the total sample, we subsequently ran the same model using 75%, 50%, and 25% segments of the total sample. We then compared the coefficients of different household income levels and different levels of education of the household head against energy use choices and the expenditure shares on different energy sources. In the multivariate probit model, sources of energy such as fuelwood, kerosene, electricity, and others are considered dependent variables. The independent variables include household demographic characteristics, labor supply, human and physical capital, and location dummies. One advantage of the multivariate probit model is that, unlike single-equation probit and logit models, the multivariate probit model simultaneously analyzes the choice of energy by the source of energy.

We follow Lin, Jensen, and Yen (2005) in formulating the multivariate model, which has four dependent variables, $y_1 \ldots y_4$:

$$y_i = 1 \;\; if \;\; \beta_i X' + \varepsilon_i > 0 \tag{1}$$

and

$$y_i = 0 \;\; if \;\; \beta_i X' + \varepsilon_i \leq 0, i = 1, 2, \ldots, 5 \tag{2}$$

where x is a vector of the explanatory variables; β_1, β_2, β_3, β_4, and β_5 are conformable parameter vectors; and ε_1, ε_2, ε_3, ε_4, and ε_5 are random errors distributed as a multivariate normal distribution with zero mean, unitary variance, and an $n\,X\,n$.

As information on household expenditure on fuel by source is available, we generated a variable by dividing the fuel expenditure for each source by total energy expenditure per household.[4] The proportion of expenditure on each energy source reveals the dependency on different sources of energy at the household level. Since the dependent variable is a fraction ranging from 0 to 1, we employed a Tobit model (censored at 0) to analyze the determinants of household energy dependency.

To examine hypotheses 1 and 2 with respect to the influence of a household's income and the level of education of the household head on expenditure on different energy sources, we ran a Tobit model first using the entire sample and then using segments equal to 75%, 50%, and 25% of the total observations. Due to a previous lack of information on expenditure on energy sources, most past studies have focused simply on choices (Rahut et al. 2014), which is an approach that fails to capture the level of dependency on energy sources as measured by expenditure size. Our study fills in this research gap by using data on expenditure to determine household dependency on particular fuel sources.

The intensity of consumption of different sources of energy is estimated using a censored Tobit model. The ratio of a household's expenditure on different sources of energy to total expenditure on energy is used to measure the intensity of consumption.

[4]For example, household expenditure on kerosene is divided by total household expenditure on fuel.

The intensity of fuel consumption is censored from the lower tail by specifying the level of intensity below which a household is not regarded as having consumed a particular source of energy. Thus, the Tobit model assumes a latent variable x_i^* that is generated by the following function:

$$x_i^* = \beta_x' z_i + \varepsilon_{xi} \tag{3}$$

where x_i^* is the latent variable that truncates the consumption of particular sources of energy, z_i is a vector of household and location characteristics, β_{xi} is a vector of coefficients to be estimated, and ε_{xi} is a scalar of error terms assumed to be independently and normally distributed with mean 0 and constant variance σ^2. Given this function, the specification of household intensity of consumption of a particular source of energy is expressed as

$$x_i = x_i^* \text{ if } x_i^* \geq d \tag{4}$$

and

$$x_i = 0 \text{ if } x_i^* < d \tag{5}$$

Where d is an established threshold that distinguishes households that use a particular source of energy from those that do not. The probability function for nonusers is

$$p(x_i^* < d) = \Phi\left(\frac{\beta_x' z_i}{\sigma}\right) \tag{6}$$

and the density for households that use a particular source of energy is

$$f(x_i | x_i^* \geq d) = \frac{f(x_i)}{p(x_i^* \geq d)} = \frac{\frac{1}{\sigma}\phi\left(\frac{x_i^* - \beta_{x_i^*}' z_i}{\sigma}\right)}{\Phi\left(\frac{\beta_{x_i^*}' z_i}{\sigma}\right)} \tag{7}$$

where $\Phi(.)$ and $\phi(.)$ are the standard normal cumulative and probability density functions, respectively. The density function represents the truncated regression model for those households whose observed consumption of a particular source of energy is greater than the threshold.

The log-likelihood function for the Tobit model is given as a summation of the probability functions for both users and nonusers of a particular source of

Table 2. **Household Energy Sources and Expenditure as a Share of the Total**

Household Energy Sources	**Frequency of Use (%)**
Kerosene	74.9
Fuelwood	85.3
Electricity	23.2
Other fuels	5.1
Expenditure per Energy Source	**Share of Total (%)**
Kerosene	31.8
Fuelwood	56.8
Electricity	9.9
Other fuels	1.5

Note: Energy choices are not mutually exclusive; that is, households can simultaneously use a mix of energy sources.
Source: Authors' calculations based on Government of Timor-Leste, Ministry of Finance. "Timor-Leste Survey of Living Standards 2007." http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTLSMS/0,,contentMDK:22764522~pagePK:64168445~piPK:64168309~theSitePK:3358997,00.html

energy:

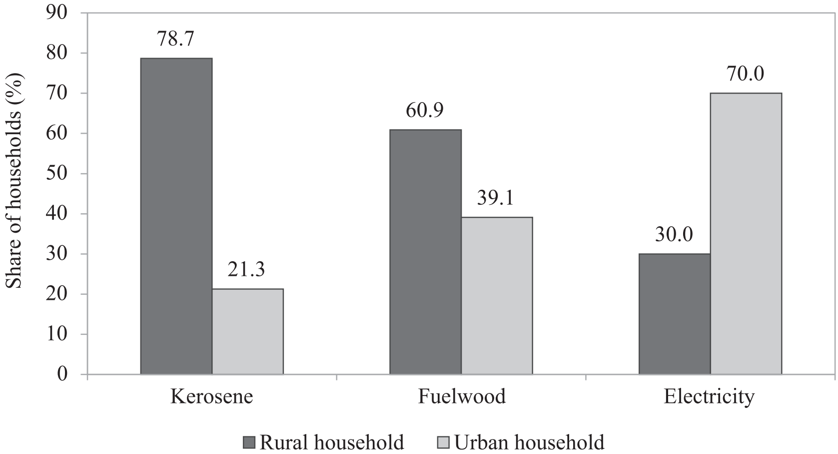
$$\ln L = \sum_{x_i^* < d} \ln\left(1 - \Phi\left(\frac{\beta'_{x_i^*} z_i}{\sigma}\right)\right) + \sum_{x_i^* \geq d} \ln \frac{1}{\sigma}\phi\left(\frac{x_i^* - \beta'_{x_i^*} z_i}{\sigma}\right) \tag{8}$$

IV. General Findings

A. Descriptive Statistics

Table 2 shows the distribution of household energy sources by use and expenditure. The majority of households in Timor-Leste use fuelwood (85.3%) and kerosene (74.9%) for domestic purposes, while only 23.2% of households use electricity. Fuelwood comprises 56.8% of total household expenditure on fuel consumption, kerosene accounts for 31.8%, and electricity comprises only 9.9%. High levels of consumption of dirty fuels like wood and kerosene have adverse effects on human health. Solid fuels like wood, dung, and coal are the most significant sources of indoor air pollution, and exposure to the byproducts of the combustion of biomass fuels, particularly wood smoke, has been linked to numerous health problems (Sanyal and Maduna 2000; Torres-Duque et al. 2008; Ingale et al. 2013; Oguntoke, Adebulehin, and Annegarn 2013; Oluwole et al. 2013). Bruce, Perez-Padilla, and Albalak (2000) reported that exposure to indoor air pollution may have been responsible at the time for nearly 2 million avoidable deaths in developing economies and about 4% of the total global disease burden.

Figure 1. **Distribution of Households Energy Sources—Rural versus Urban**



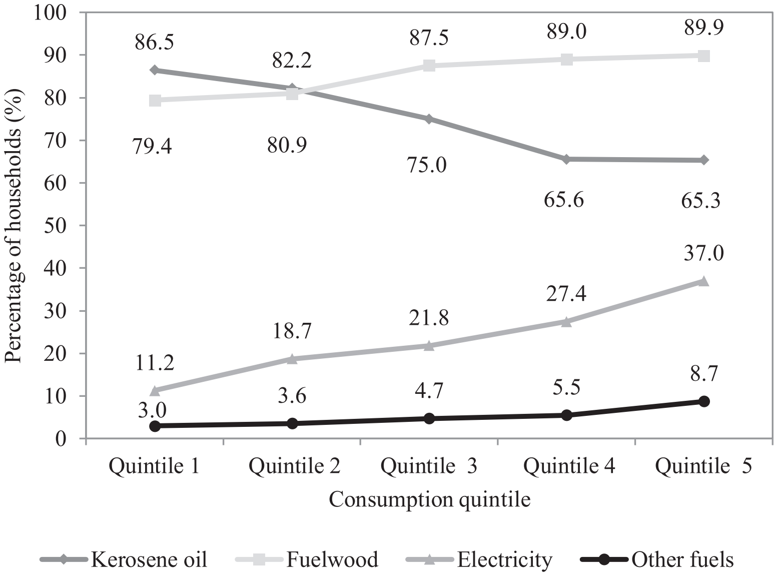
Source: Authors' calculations based on Government of Timor-Leste, Ministry of Finance. "Timor-Leste Survey of Living Standards 2007." http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTLSMS/0,,contentMDK:22764522~pagePK:64168445~piPK:64168309~theSitePK:3358997,00.html

Figure 1 shows the distribution of household energy sources by location (rural versus urban). We find that 78.7% of the households in Timor-Leste using kerosene oil and 60.9% of those using fuelwood are located in rural areas. Among all households using electricity, only 30% are located in rural areas. The majority of rural households use dirty fuel and only a small proportion of all rural households use clean energy like electricity.

Globally, about 50% of all households and about 90% of rural households use solid fuels such as coal and biomass as their main domestic source of energy, which means that approximately 50% of the world's population—more than 3 billion people—are exposed to the harmful effects of the combustion of these fuels (Torres-Duque et al. 2008).

Figure 2 presents household energy sources by consumption quintile, which shows that the percentage of households using electricity increases across consumption quintiles while the percentage of households using kerosene decreases. Only 11.2% of households in the first consumption quintile (poorest 20%) use electricity, while 27.4% of households in the fourth quintile and 37% of those in the fifth quintile (richest 20%) use electricity. About 86.5% of households in the first quintile use kerosene, while 65.3% of those in the fifth quintile use kerosene. The percentage of households using fuelwood also increases with rising income, indicating that the economic status of the household influences the consumption of fuelwood, which is contrary to the general finding that with an increase in income the percentage of households using fuelwood decreases (Barnes and Floor 1999; Heltberg 2005; Rao and Reddy 2007; Pachauri and Jiang 2008; Kwakwa, Wiafe, and Alhassan 2013; Rahut et al. 2014; Behera et al. 2015). In Timor-Leste, as in many

Figure 2. **Distribution of Household Energy Sources by Consumption Quintile**



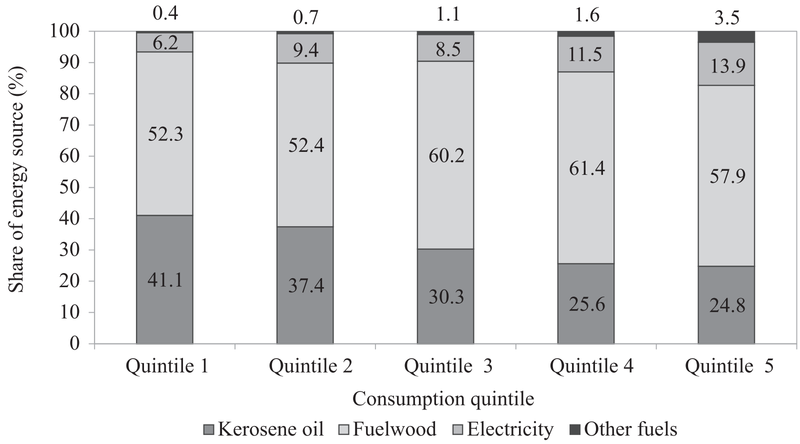
Source: Authors' calculations based on Government of Timor-Leste, Ministry of Finance. "Timor-Leste Survey of Living Standards 2007." http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTLSMS/0,,contentMDK:22764522~pagePK:64168445~piPK:64168309~theSitePK:3358997,00.html

developing economies, fuelwood is relatively cheap and available, leading to higher levels of consumption. Furthermore, fuelwood's use for domestic energy purposes is widely accepted in Timor-Leste. The abundance of and access to fuelwood, as well as cultural norms, might even encourage higher levels of fuelwood use among relatively wealthy households in Timor-Leste.

Figure 3 presents the shares of household energy expenditure across consumption quintiles. Using household expenditure as the unit of measurement, electricity consumption as a share of total household energy consumption increases as household income increases, while the share of kerosene consumption decreases with an increase in income. For the poorest 20% of households, electricity comprises 6.2% of total household energy consumption, while for the richest 20% it accounts for 13.9%. Kerosene comprises 41.1% of energy consumption among the poorest quintile of households and only 24.8% of energy consumption among the richest quintile. Figure 3 demonstrates that households in Timor-Leste with higher incomes tend to depend more on clean energy such as electricity than dirty fuels such as kerosene, confirming the findings of other studies on household energy consumption in developing economies (Heltberg 2004, Pachauri 2004, Rao and Reddy 2007, Reddy and Srinivas 2009, Rahut et al. 2014).

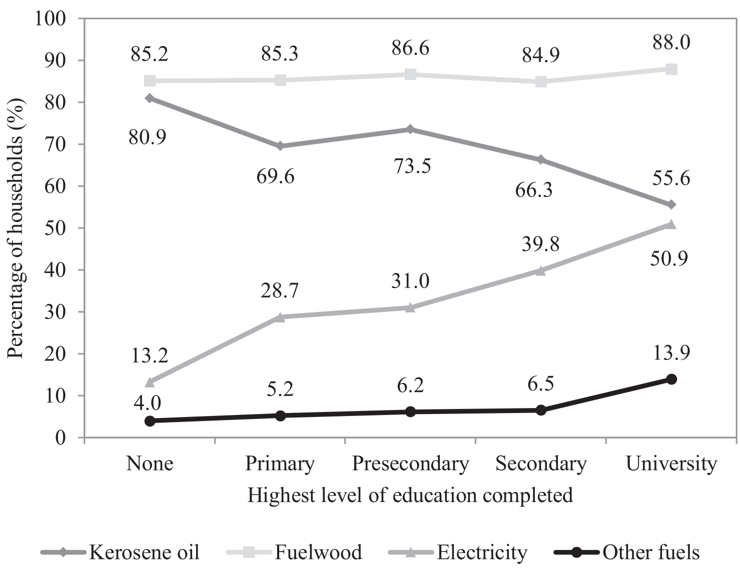
Figure 4 presents household energy use patterns based on the level of education of the head of the household. The percentage of households using kerosene

Figure 3. **Distribution of Household Energy Expenditure by Consumption Quintile**



Source: Authors' calculations based on Government of Timor-Leste, Ministry of Finance. "Timor-Leste Survey of Living Standards 2007." http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTLSMS/0,,contentMDK:22764522~pagePK:64168445~piPK:64168309~theSitePK:3358997,00.html

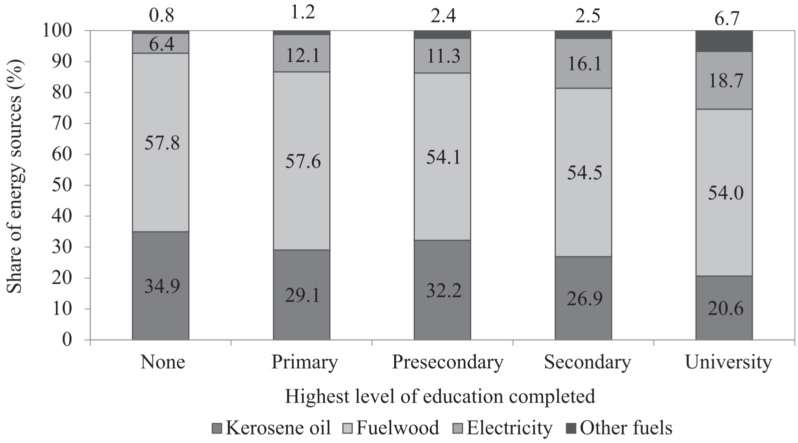
Figure 4. **Distribution of Household Energy Sources by Level of Education of the Household Head**



Source: Authors' calculations based on Timor-Leste Living Standards Survey Data 2007.

falls with an increase in the level of education of the household head, while the percentage of households using electricity rises with an increase in the household head's education level. Only 13.2% of households headed by individuals without an education use electricity, while 50.9% of households headed by an individual

Figure 5. **Distribution of Household Energy Expenditure by Level of Education of the Household Head**



Source: Authors' calculations based on Government of Timor-Leste, Ministry of Finance. "Timor-Leste Survey of Living Standards 2007." http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTLSMS/0,,contentMDK:22764522~pagePK:64168445~piPK:64168309~theSitePK:3358997,00.html

with a university degree use electricity. About 80.9% of households headed by an individual without an education use kerosene, while 55.6% of households with a university-educated head use kerosene. Interestingly, the percentage of households using fuelwood is fairly constant across levels of education.

Figure 5 presents household expenditure shares for different sources of energy by the level of education of the household head. The share of expenditure utilized for electricity increases with an increase in the level of education of the household head, while the share of expenditure for kerosene decreases. Electricity accounts for only 6.4% of total energy consumption expenditure for households headed by an individual with no formal education, compared with 18.7% for households headed by those with a university degree. In households headed by someone without any formal education, kerosene contributes 34.9% of energy consumption expenditure, compared with 20.6% for households with a university-educated head. Figures 4 and 5 demonstrate that as incomes and education levels rise, households tend to use more and spend more on clean energy such as electricity.

B. Empirical Model

1. Household Energy Choices—Estimation of Multivariate Probit Model

Table 3 presents the pairwise correlation coefficients showing the relationship between various energy source choices made by households. Overall, the result shows a positive correlation among dirty energy sources and a negative relationship

Table 3. **Correlation Coefficients of Household Energy Sources**

Household energy sources for domestic use	Correlation Coefficient	Standard Error
Kerosene and fuelwood	0.06	0.04
Kerosene and electricity	−0.60***	0.04
Kerosene and other fuels	0.07	0.08
Fuelwood and electricity	−0.34***	0.04
Fuelwood and other fuels	−0.20**	0.08
Electricity and other fuels	0.15**	0.07

Notes: Correlation coefficients are derived from the multivariate probit estimations in Table 4. * = 10% level of significance, ** = 5% level of significance, *** = 1% level of significance. LR test for rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0: $chi^2(6) = 455669$ Prob. > chi2 = 0.0000.
Source: Authors' calculations.

between clean and dirty sources of energy. A positive and significant correlation is observed between the use of kerosene and fuelwood, both of which are considered dirty sources of energy. A positive correlation is noted between kerosene and other fuels. Interestingly, Table 3 shows negative and significant correlations between kerosene and electricity, and fuelwood and electricity, indicating that a household which depends on electricity as a source of energy also tends to use fuels other than kerosene or fuelwood. This is likely because of the relatively high purchasing power of households that use electricity. Table 3 generally confirms that households usually depend on more than a single source of energy. For example, a household may depend on electricity for lighting and fuelwood for cooking. Thus, energy sources are not mutually exclusive within a single household, which allows us to employ a multivariate probit model in estimating household choices of different energy sources.

Table 4 presents the estimated functions of household energy sources in relation to household characteristics. Results from the multivariate probit on energy choices show that with an increase in the age of the household head, the likelihood of using electricity increases up until 54 years of age. The coefficient of the female-headed household variable (yes = 1) is negative and significant for kerosene and other fuels, and is positive and highly significant for fuelwood ($P < 0.00$). This finding confirms that in developing economies, female members are more involved in collecting fuelwood from forests than their male counterparts (Heltberg, Arndt, and Sekhar 2000). Consequently, a female-headed household is more likely to choose fuelwood as a source of energy (Reddy and Srinivas 2009). The multiplicative dummies in Table 4, which are generated by multiplying the female-headed household dummy with consumption quintiles, show that relatively rich female-headed households are less likely to use fuelwood as a source of energy since there is a higher opportunity cost of collecting fuelwood for these households.

Table 4. **Functions Estimated Using a Multivariate Probit Model to Explain Household Energy Choices**

Estimation Method	**Multivariate Probit**			
Dependent variables: Energy source	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**
Demographics				
Age, household head	0.001	−0.018	0.043***	0.048*
	(0.01)	(0.01)	(0.01)	(0.03)
Age squared, household head	−0.00003	0.0001	−0.0004***	−0.001**
	(0.00)	(0.00)	(0.00)	(0.00)
Female-headed household[a,b]	0.01	0.71***	−0.02	0.51
	(0.23)	(0.22)	(0.26)	(0.43)
Household size (no. of family members)	−0.05***	0.11***	0.08***	0.08***
	(0.01)	(0.02)	(0.01)	(0.02)
Human capital				
Primary completed[a,c]	−0.15*	−0.17**	0.43***	−0.050
	(0.08)	(0.08)	(0.08)	(0.13)
Presecondary completed[a,c]	−0.07	−0.0033	0.61***	0.16
	(0.11)	(0.12)	(0.11)	(0.17)
Secondary completed[a,c]	−0.17*	−0.34***	0.58***	−0.12
	(0.10)	(0.10)	(0.10)	(0.15)
University completed[a,c]	−0.47**	−0.63***	0.50***	0.57**
	(0.18)	(0.23)	(0.18)	(0.27)
Consumption quintile				
Consumption quintile 2[a,d]	0.03	0.18*	0.30***	0.53***
	(0.11)	(0.10)	(0.11)	(0.18)
Consumption quintile 3[a,d]	−0.17	0.59***	0.38***	0.70***
	(0.11)	(0.11)	(0.11)	(0.18)
Consumption quintile 4[a,d]	−0.40***	0.71***	0.57***	1.02***
	(0.11)	(0.11)	(0.12)	(0.18)
Consumption quintile 5[a,d]	−0.38***	0.79***	0.84***	1.13***
	(0.12)	(0.14)	(0.13)	(0.19)
Location				
Rural household[e]	0.86***	−0.33***	−0.55***	0.07
	(0.06)	(0.07)	(0.07)	(0.10)
Gender and consumption quintile				
Female-headed household × consumption quintile 2	−0.13	−0.55*	0.14	−1.04*
	(0.30)	(0.29)	(0.32)	(0.54)
Female-headed household × consumption quintile 3	−0.38	−0.82***	0.07	−0.58
	(0.29)	(0.30)	(0.32)	(0.60)
Female-headed household × consumption quintile 4	−0.06	−0.61**	−0.07	−0.76
	(0.28)	(0.30)	(0.32)	(0.54)
Female-headed household × consumption quintile 5	−0.18	−0.54*	−0.14	−0.86
	(0.28)	(0.29)	(0.30)	(0.56)
Regions				
Region 2 (Manatuto, Manufahi, Ainaro)[d,f]	1.23***	−0.64***	−0.40***	0.005
	(0.10)	(0.09)	(0.08)	(0.20)
Region 3 (Dili, Aileu, Ermera)[d,f]	0.77***	−0.18**	−1.02***	−0.44***
	(0.08)	(0.09)	(0.09)	(0.16)
Region 4 (Bobonaro, Cova Lima, Liquiçá)[d,f]	1.11***	0.21**	−0.70***	0.20
	(0.09)	(0.09)	(0.09)	(0.16)
Region 5 (Oecusse)[d,f]	1.62***	1.00***	−0.91***	1.39***
	(0.15)	(0.17)	(0.08)	(0.16)

Continued.

Table 4. *Continued.*

Estimation Method	**Multivariate Probit**			
Dependent variables: Energy source	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**
Constant	−0.08	1.10***	−2.25***	−4.11***
	(0.35)	(0.37)	(0.38)	(0.66)
No. of observations	4,357			
Wald Chi^2 (84)	1,586.27			
Prob. > chi2	0.000			
Log pseudolikelihood	−233,621.94			

[a]Dummy variables
[b]Excluded category: male-headed households
[c]Excluded category: household head with no education
[d]Excluded category: consumption quintile 1
[e]Excluded category: urban households
[f]Excluded region: Region I: (Baucau, Lautém, Viqueque)
Notes: Standard errors in parentheses. * = 10% level of significance, ** = 5% level of significance, *** = 1% level of significance.
Source: Authors' calculations.

The findings confirm that, while in general households headed by a female are more likely to use fuelwood as their primary source of energy, relatively wealthy female-headed households are less likely to use fuelwood as their primary source of energy.

The coefficient of household size is positive and significant with respect to the use of fuelwood, electricity, and other fuels, while it is negative and significant for kerosene. The findings in Table 4 strongly support the first part of hypothesis (2), which is that household size positively and significantly influences the choice of and expenditure on fuelwood, electricity, and energy sources other than kerosene. The positive relationship between household size and fuelwood can be explained by the increased availability of family labor to collect fuelwood and the greater demand for energy in larger households. This finding supports results from past studies on household energy use in developing economies that illustrate the positive correlation between fuelwood and household size (Heltberg 2004).

In order to examine the influence of education on energy choices, which is covered in the second part of hypothesis (1), we included four dummies for the level of education of the household head: primary completed (1), presecondary completed (2), secondary completed (3), and university completed (4). Thus, the excluded category is no education (0). The results in Table 4 show that compared with households headed by individuals with no education, the probability of choosing kerosene and wood as sources of fuel decreases as the level of education rises. For kerosene, the coefficients of the variables are as follows: primary completed (−0.15 [P < 0.10]), secondary completed (−0.17 [P < 0.10]), and university completed (−0.47 [P < 0.05%]). For fuelwood, the coefficients of the variables are as follows: (−0.17 [P < 0.05]), secondary completed (−0.34 [P < 0.10]), and university completed (−0.63 [P < 0.05]). The coefficients of the dummies for presecondary completed for kerosene and fuelwood are both negative but insignificant. Table 4 clearly shows that the probability of the choice of electricity for domestic energy use increases with an increase in the level of education of the household head. In the energy choice model, the coefficient of the primary completed variable for the household head is 0.43, for presecondary completed it is 0.61, for secondary completed it is 0.58, and for a university degree it is 0.5. All of these coefficients are significant at the 1% level.

To examine hypothesis (1), which covers the effects of income on the choice of domestic energy use, we used the consumption quintiles as independent variables in the estimated functions shown in Table 4. The results indicate that the likelihood of the choice of kerosene decreases, while the choice of fuelwood, electricity, and other fuels increases progressively in relation to consumption quintiles. For example, the coefficients for the choice of kerosene are −0.40 (P < 0.00) for consumption quintile 4 and −0.38 (P < 0.00) for consumption quintile 5. (Consumption quintile 1 is the base in this case.) The coefficients for the choice of fuelwood are 0.18 (significant at the 10% level) for consumption quintile 2, 0.59 (significant at the 1% level) for consumption quintile 3, 0.71 (significant at the 1% level) for consumption quintile 4, and 0.79 (significant at the 1% level) for consumption quintile 5. The coefficients for the choice of electricity are 0.3 for consumption quintile 2, 0.38 for consumption quintile 3, 0.57 for consumption quintile 4, and 0.84 for consumption quintile 5. All are significant at the 1% level. Coefficients for the choice of other energy sources are 0.53 for consumption quintile 2, 0.7 for consumption quintile 3, 1.02 for consumption quintile 4, and 1.13 for consumption quintile 4. All are significant at the 1% level. The findings indicate that relatively affluent households are more likely to choose fuelwood as well as clean energy such as electricity as the main sources of energy for their homes.

The coefficients of the rural household dummy (yes = 1) are 0.86 (significant at the 1% level) for the choice of kerosene, −0.33 (significant at the 1% level) for fuelwood, and −0.55 (significant at the 1% level) for electricity, indicating that, when compared with urban households, rural households are more likely to choose kerosene and less likely to choose fuelwood and electricity.

To capture the effects of regional heterogeneity in fuel choices among sampled households, four regional dummies for five regions were included in estimating the functions in Table 4. The base region is Region 1, comprising Baucau, Lautem, and Viqueque districts. The regional dummies in Table 4 show that compared with households located in Region 1, households in all other regions are more likely to use kerosene and less likely to use electricity as a source of fuel. The households in Region 4, comprising Bobonaro, Coval Mia, and Liquica districts, and Region 5, comprising Oecusse district, are more likely to choose fuelwood than households located in the base region.

2. Intensity of Consumption of Energy by Sources—Results and Discussion from the Tobit Model

The multivariate probit model in Table 4 only assesses the choice of a particular energy source at the household level. It does not tell the extent to which households are dependent on different sources of energy. In order to assess a household's dependency on a particular source of energy, we employed a tobit model in which the dependent variable is expenditure on a particular source of energy divided by the total energy expenditure of a household (Table 5).

Estimated functions in Table 5 present the intensity of a particular energy source used by households. Similar to the energy choice model (Table 4), the results show that with an increase in the age of the household head the consumption of both electricity and other fuels increases in relation to total energy consumption. However, dependency on electricity and other fuels, in terms of the share of household expenditure, declines with the age of the household head. Female-headed households are less likely to depend on kerosene and more likely to depend on fuelwood than their male-headed counterparts. However, there is no statistically significant relationship between wealthy female-headed households and dependency on a particular fuel. This means that the share of expenditure on all fuels almost remains the same among female-headed households irrespective of income. With an increase in family size, households are more likely to be dependent on fuelwood, electricity, and other fuels, while dependence on kerosene decreases as households expand in size.

Importantly, there is no significant relationship between the level of education of the household head and dependency on kerosene. This means that the use of kerosene remains nearly the same among all households irrespective of the level of education of the household head. The degree of dependency on fuelwood decreases with an increase in the level of education of the household head. In contrast, the degree of dependency on electricity increases with an increase in the level of education of the household head. The function explaining expenditure share on fuelwood shows that the coefficient of the dummy for a household head who has completed a primary education is −0.05 (significant at the 1% level), a presecondary education is 0.06 (significant at the 1% level), a secondary education is −0.10 (significant at the 1% level), and a university education is −0.15 (significant at the 5% level). In contrast, the coefficient of the dummy variable for a household head with a primary education is 0.29, a presecondary education is 0.37, a secondary education is 0.42, and a university education is 0.37. All of these coefficients are significant at the 1% level. In the case of other fuels, the dummy variable for a household head with a university degree is positive and significant at the 5% level.

Table 5 shows that with an increase in wealth, dependency on kerosene decreases and dependency on fuelwood, electricity, and other fuels increases. The coefficient of the rural dummy is 0.24 (significant at the 1% level) for the share of

Table 5. **Functions Estimated Using a Two-Limit Tobit Model to Explain Household Expenditure on Different Energy Sources**

Dependent variables	**Share of expenditure on kerosene**	**Share of expenditure on fuelwood**	**Share of expenditure on electricity**	**Share of expenditure on other fuels**
Demographics				
Age, household head	0.0017	−0.0061*	0.026**	0.040*
	(0.00)	(0.00)	(0.01)	(0.02)
Age squared, household head	−0.0000096	0.000044	−0.00021*	−0.00052**
	(0.00)	(0.00)	(0.00)	(0.00)
Female-headed household[a,b]	−0.12***	0.10***	0.0090	0.41
	(0.04)	(0.04)	(0.19)	(0.34)
Household size (no. of family members)	−0.032***	0.020***	0.047***	0.068***
	(0.00)	(0.00)	(0.01)	(0.02)
Human capital				
Primary completed[a,c]	−0.0019	−0.055***	0.29***	−0.072
	(0.02)	(0.02)	(0.06)	(0.10)
Presecondary completed[a,c]	0.0061	−0.066***	0.37***	0.14
	(0.03)	(0.02)	(0.08)	(0.15)
Secondary completed[a,c]	0.0078	−0.10***	0.42***	−0.062
	(0.02)	(0.02)	(0.07)	(0.12)
University completed[a,c]	−0.038	−0.15**	0.37***	0.50**
	(0.07)	(0.06)	(0.13)	(0.21)
Income				
Consumption quintile 2[a,d]	−0.043*	0.022	0.19**	0.37**
	(0.02)	(0.02)	(0.09)	(0.15)
Consumption quintile 3[a,d]	−0.14***	0.12***	0.16**	0.51***
	(0.02)	(0.02)	(0.08)	(0.15)
Consumption quintile 4[a,d]	−0.19***	0.13***	0.32***	0.75***
	(0.02)	(0.02)	(0.09)	(0.14)
Consumption quintile 5[a,d]	−0.20***	0.10***	0.48***	0.88***
	(0.03)	(0.03)	(0.09)	(0.15)
Location				
Rural household[a,e]	0.24***	−0.15***	−0.27***	0.022
	(0.02)	(0.01)	(0.04)	(0.08)
Gender and wealth				
Female-headed household × consumption quintile 2	0.088	−0.071	−0.047	−0.83**
	(0.06)	(0.06)	(0.23)	(0.42)
Female-headed household × consumption quintile 3	0.057	−0.086	0.0094	−0.51
	(0.06)	(0.06)	(0.24)	(0.46)
Female-headed household × consumption quintile 4	0.075	−0.077	−0.018	−0.56
	(0.06)	(0.05)	(0.24)	(0.43)
Female-headed household × consumption quintile 5	0.074	−0.046	−0.11	−0.69
	(0.06)	(0.05)	(0.22)	(0.44)
Regions				
Region 2 (Manatuto, Manufahi, Ainaro)[a,f]	0.38***	−0.34***	−0.12**	−0.065
	(0.02)	(0.02)	(0.06)	(0.16)
Region 3 (Dili, Aileu, Ermera)[a,f]	0.23***	−0.11***	−0.57***	−0.38***
	(0.02)	(0.02)	(0.06)	(0.14)
Region 4 (Bobonaro, Cova Lima, Liquiçá)[a,f]	0.27***	−0.15***	−0.35***	0.11
	(0.02)	(0.02)	(0.06)	(0.13)
Region 5 (Oecusse)[a,f]	0.10***	0.064***	−0.68***	0.92***
	(0.02)	(0.02)	(0.05)	(0.12)

Continued.

Table 5. *Continued.*

Dependent variables	Share of expenditure on kerosene	Share of expenditure on fuelwood	Share of expenditure on electricity	Share of expenditure on other fuels
Constant	0.12	0.81***	−1.64***	−3.18***
	(0.08)	(0.08)	(0.28)	(0.58)
Sigma	0.35***	0.34***	0.77***	0.80***
	(0.01)	(0.01)	(0.03)	(0.06)
No. of observations	4,357	4,357	4,357	4,357
Left-censored observations at tker_exp <= 0	1,093	639	3,345	4,135
Uncensored observations	3,264	3,718	1,012	222
Right-censored observations	0	0	0	0
Pseudo R^2	0.21	0.16	0.10	0.19
F	44.04	30.90	25.80	10.93
Prob. > F	0.00	0.00	0.00	0.00
Log pseudolikelihood	−89,439.94	−83,897.11	−78,432.60	−20,503.39

[a]Dummy variables
[b]Excluded category: male-headed households
[c]Excluded category: household head with no education
[d]Excluded category: consumption quintile 1
[e]Excluded category: urban households
[f]Excluded region: Region I: (Baucau, Lautém, Viqueque)
Notes: Robust standard errors in parentheses. *** = 1% level of significance, ** = 5% level of significance, * = 10% level of significance.
Source: Authors' calculations.

expenditure on kerosene, indicating that rural households are more dependent on kerosene than urban households. The coefficients of the rural dummy, however, are −0.15 and −0.27, respectively, for fuelwood and electricity (both are significant at the 1% level), indicating that fuelwood and electricity are less important as sources of energy to rural households than urban households.

The regional dummies included in Table 5 show that compared with Region 1, households in all other regions are more likely to depend on kerosene and less likely to depend on wood and electricity.

3. Sensitivity Analysis

In Tables 6 and 7, we apply the same estimation methods (multivariate probit for estimating the energy choice function and Tobit for estimating the expenditure share function) to reestimate the functions by using different combinations of the samples. Table 6 presents estimated functions applying a multivariate probit model explaining household choices of different energy sources. In the first segment of Table 6, we include 75% of total sampled households (3,267 out of 4,357). In the second segment, we include 50% (2,178) of total sampled households. In the third segment, we include 25% (1,089) of total sampled households.

Table 6. **Multivariate Probit Model Explaining the Household Energy Choices of 75%, 50%, and 25% of Total Sampled Households**

Data Segment	75%				50%				25%			
Dependent variable: Energy sources	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**
Demographics												
Age, household head	0.005	−0.02	0.05**	0.070**	0.0033	−0.044**	0.041*	0.059	0.007	0.038	0.066**	0.11*
	(0.02)	(0.02)	(0.02)	(0.04)	(0.02)	(0.02)	(0.02)	(0.05)	(0.03)	(0.03)	(0.03)	(0.06)
Age squared, household head	−0.0001	0.0001	−0.0004**	−0.00084**	−0.000077	0.00043**	−0.00035	−0.00078*	−0.0001	−0.00048*	−0.00054*	−0.0012*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Female-headed household[a,b]	0.07	0.83***	0.09	0.51	0.85**	0.97***	−0.12	0.98*	−0.71**	0.65	0.39	−4.22***
	(0.25)	(0.25)	(0.26)	(0.51)	(0.38)	(0.31)	(0.39)	(0.56)	(0.36)	(0.42)	(0.37)	(0.39)
Household size (no. of family members)	−0.05***	0.09***	0.10***	0.079***	−0.049***	0.10***	0.082***	0.083***	−0.05**	0.076**	0.11***	0.077*
	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.04)	(0.03)	(0.04)
Human capital												
Primary completed[a,c]	−0.20**	−0.16	0.46***	−0.015	−0.24**	−0.071	0.46***	−0.098	−0.15	−0.40**	0.59***	0.30
	(0.09)	(0.10)	(0.10)	(0.15)	(0.11)	(0.12)	(0.12)	(0.18)	(0.15)	(0.17)	(0.16)	(0.26)
Presecondary completed[a,c]	−0.09	0.030	0.67***	0.070	−0.080	0.025	0.69***	0.24	−0.088	−0.019	0.69***	−0.45
	(0.12)	(0.14)	(0.13)	(0.20)	(0.16)	(0.18)	(0.16)	(0.22)	(0.21)	(0.24)	(0.21)	(0.33)
Secondary completed[a,c]	−0.23**	−0.33***	0.72***	−0.20	−0.30**	−0.32**	0.73***	−0.37	−0.10	−0.37*	0.75***	0.035
	(0.11)	(0.12)	(0.11)	(0.18)	(0.14)	(0.15)	(0.14)	(0.25)	(0.19)	(0.20)	(0.19)	(0.28)
University completed[a,c]	−0.45**	−0.69**	0.46**	0.48	−0.50*	−0.87**	0.39	0.26	−0.44	−0.37	0.65*	1.14**
	(0.23)	(0.29)	(0.20)	(0.33)	(0.30)	(0.36)	(0.24)	(0.45)	(0.34)	(0.53)	(0.34)	(0.48)
Income												
Consumption quintile 2[a,d]	0.11	0.29***	0.18	0.44**	0.24	0.46***	0.20	0.45	−0.089	−0.095	0.037	0.30
	(0.12)	(0.11)	(0.13)	(0.22)	(0.15)	(0.13)	(0.16)	(0.28)	(0.21)	(0.19)	(0.22)	(0.33)
Consumption quintile 3[a,d]	−0.07	0.53***	0.20	0.77***	0.073	0.64***	0.096	0.78***	−0.31	0.28	0.41*	0.58*
	(0.12)	(0.12)	(0.13)	(0.20)	(0.15)	(0.14)	(0.17)	(0.27)	(0.20)	(0.22)	(0.22)	(0.30)
Consumption quintile 4[a,d]	−0.37***	0.60***	0.58***	0.98***	−0.25*	0.75***	0.61***	1.19***	−0.59***	0.30	0.43*	0.59*
	(0.12)	(0.13)	(0.14)	(0.22)	(0.15)	(0.16)	(0.17)	(0.28)	(0.20)	(0.21)	(0.24)	(0.32)
Consumption quintile 5[a,d]	−0.31**	0.73***	0.85***	1.23***	−0.19	0.82***	0.79***	1.68***	−0.51**	0.59**	0.89***	0.34
	(0.14)	(0.16)	(0.15)	(0.22)	(0.17)	(0.20)	(0.18)	(0.28)	(0.22)	(0.24)	(0.24)	(0.35)

Continued.

Table 6. *Continued.*

Data Segment	75%				50%				25%			
Dependent variable: Energy sources	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**
Location												
Rural household	0.81***	−0.42***	−0.51***	0.044	0.90***	−0.38***	−0.52***	0.18	0.63***	−0.52***	−0.48***	−0.14
	(0.07)	(0.08)	(0.08)	(0.12)	(0.09)	(0.09)	(0.10)	(0.16)	(0.12)	(0.13)	(0.13)	(0.18)
Gender and wealth												
Female-headed household × consumption quintile 2	−0.33	−0.73**	0.30	−0.88	−1.31***	−0.95**	0.51	−0.97	0.94*	−0.37	0.28	−0.68
	(0.33)	(0.32)	(0.32)	(0.61)	(0.46)	(0.39)	(0.44)	(0.69)	(0.51)	(0.57)	(0.52)	(0.56)
Female-headed household × consumption quintile 3	−0.45	−0.91***	0.0041	−0.62	−1.28***	−1.14***	0.35	−1.62**	0.44	−0.50	−0.76	4.40***
	(0.32)	(0.34)	(0.33)	(0.67)	(0.45)	(0.40)	(0.46)	(0.76)	(0.53)	(0.59)	(0.51)	(0.69)
Female-headed household × consumption quintile 4	0.047	−0.83**	−0.19	−1.07*	−0.64	−0.98**	−0.055	−1.66**	0.73	−0.69	−0.23	3.96***
	(0.31)	(0.34)	(0.36)	(0.60)	(0.44)	(0.42)	(0.48)	(0.70)	(0.48)	(0.58)	(0.58)	(0.69)
Female-headed household × consumption quintile 5	−0.28	−0.64**	−0.28	−0.99	−1.10**	−0.80**	−0.19	−1.47**	0.51	−0.52	−0.29	3.75***
	(0.30)	(0.32)	(0.31)	(0.65)	(0.44)	(0.39)	(0.45)	(0.75)	(0.46)	(0.56)	(0.46)	(0.67)
Region												
Region 2 (Manatuto, Manufahi, Ainaro)[a,f]	1.29***	−0.71***	−0.42***	0.049	1.27***	−0.69***	−0.28**	−0.21	1.33***	−0.80***	−0.68***	0.35
	(0.11)	(0.10)	(0.10)	(0.21)	(0.13)	(0.12)	(0.12)	(0.26)	(0.19)	(0.17)	(0.17)	(0.37)
Region 3 (Dili, Aileu, Ermera)[a,f]	0.87***	−0.20**	−1.03***	−0.47**	0.83***	−0.20	−0.92***	−0.46**	0.90***	−0.22	−1.33***	−1.01***
	(0.09)	(0.10)	(0.11)	(0.19)	(0.11)	(0.13)	(0.14)	(0.21)	(0.15)	(0.18)	(0.19)	(0.30)
Region 4 (Bobonaro, Cova Lima, Liquiçá)[a,f]	1.21***	0.20*	−0.79***	0.24	1.25***	0.30**	−0.77***	−0.17	1.17***	0.031	−0.87***	0.71**
	(0.11)	(0.11)	(0.11)	(0.19)	(0.13)	(0.14)	(0.14)	(0.24)	(0.17)	(0.17)	(0.19)	(0.34)
Region 5 (Oecusse)[a,f]	1.60***	0.93***	−0.90***	1.43***	1.55***	0.89***	−0.79***	1.57***	1.73***	1.09***	−1.13***	1.32***
	(0.17)	(0.20)	(0.09)	(0.19)	(0.21)	(0.24)	(0.11)	(0.20)	(0.22)	(0.26)	(0.17)	(0.42)

Continued.

Table 6. *Continued.*

Data Segment	75%				50%				25%			
Dependent variable: Energy sources	Kerosene	Fuelwood	Electricity	Other Fuels	Kerosene	Fuelwood	Electricity	Other Fuels	Kerosene	Fuelwood	Electricity	Other Fuels
Constant	−0.23	1.16***	−2.56***	−4.60***	−0.30	1.57***	−2.33***	−4.47***	−0.057	0.53	−3.11***	−5.34***
	(0.41)	(0.42)	(0.46)	(0.81)	(0.51)	(0.51)	(0.56)	(1.02)	(0.72)	(0.75)	(0.73)	(1.31)
atrho21	0.027				0.056				0.011			
	(0.05)				(0.06)				(0.08)			
atrho31	−0.57***				−0.58***				−0.50***			
	(0.05)				(0.06)				(0.09)			
atrho41	−0.015				0.099				0.00014			
	(0.09)				(0.11)				(0.18)			
atrho32	−0.30***				−0.31***				−0.36***			
	(0.05)				(0.06)				(0.08)			
atrho42	−0.21**				−0.20**				−0.25**			
	(0.09)				(0.10)				(0.12)			
atrho43	0.10				0.11				0.073			
	(0.07)				(0.09)				(0.13)			
No. of observations	3,267				2,178				1,089			
Walt Chi^2 (84)	1,260.32				1,074.14				1,806.16			
Prob. > chi^2	0.00				0.00				0.00			
Log pseudolikelihood	−174,289.56				−114,358.53				−57,630.37			

[a]Dummy variables
[b]Excluded category: male-headed households
[c]Excluded category: household head with no education
[d]Excluded category: consumption quintile 1
[e]Excluded category: urban households
[f]Excluded region: Region I: (Baucau, Lautém, Viqueque)
Notes: Robust standard errors in parentheses. *** = 1% level of significance, ** = 5% level of significance, * = 10% level of significance.
Source: Authors' calculations.

Table 7. **Two-Limit Tobit Model Explaining the Expenditure Share of Different Energy Sources of 75%, 50%, and 25% of Total Sampled Households**

Data Segment	**75%**				**50%**				**25%**			
Dependent variable: Energy sources	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**
Demographics												
Age, household head	0.00097	−0.0071*	0.042***	0.053**	0.0017	−0.0094**	0.053***	0.061**	0.00082	−0.0040	0.023	0.039***
	(0.00)	(0.00)	(0.01)	(0.03)	(0.00)	(0.00)	(0.02)	(0.03)	(0.01)	(0.01)	(0.02)	(0.00)
Age squared,	−0.0000062	0.000054	−0.00035***	−0.00069**	−0.000015	0.000075*	−0.00044***	−0.00074**	−0.0000049	0.000032	−0.00021	−0.00063***
household head	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Female-headed	−0.14***	0.11***	0.094	0.073	−0.14***	0.099**	0.15	0.068	−0.15**	0.14	0.00017	−3.14***
household[a,b]	(0.04)	(0.04)	(0.20)	(0.27)	(0.05)	(0.04)	(0.23)	(0.28)	(0.07)	(0.09)	(0.37)	(0.05)
Household size (no. of	−0.033***	0.022***	0.039***	0.073***	−0.033***	0.023***	0.039***	0.074***	−0.033***	0.020***	0.031*	0.073***
family members)	(0.00)	(0.00)	(0.01)	(0.02)	(0.00)	(0.00)	(0.01)	(0.03)	(0.01)	(0.01)	(0.02)	(0.01)
Human capital												
Primary completed[a,c]	−0.0062	−0.059***	0.31***	−0.046	0.0010	−0.083***	0.41***	0.038	−0.023	−0.0058	0.12	−0.39***
	(0.02)	(0.02)	(0.07)	(0.11)	(0.03)	(0.02)	(0.08)	(0.12)	(0.04)	(0.04)	(0.12)	(0.03)
Presecondary	0.0065	−0.076***	0.42***	0.17	0.0080	−0.093***	0.53***	0.17	−0.0026	−0.037	0.21	0.15***
completed[a,c]	(0.03)	(0.03)	(0.09)	(0.16)	(0.04)	(0.04)	(0.12)	(0.19)	(0.05)	(0.04)	(0.13)	(0.04)
Secondary	0.014	−0.12***	0.50***	−0.062	0.030	−0.15***	0.54***	−0.063	−0.025	−0.066	0.47***	−0.100***
completed[a,c]	(0.03)	(0.03)	(0.08)	(0.13)	(0.03)	(0.03)	(0.11)	(0.15)	(0.05)	(0.04)	(0.12)	(0.03)
University	−0.057	−0.13*	0.44***	0.29	0.014	−0.22**	0.66***	0.35	−0.17	0.010	0.17	0.18***
completed[a,c]	(0.09)	(0.07)	(0.14)	(0.22)	(0.11)	(0.09)	(0.19)	(0.26)	(0.14)	(0.10)	(0.22)	(0.04)
Income												
Consumption quintile	−0.053**	0.051*	0.073	0.32**	−0.062*	0.059*	0.10	0.34*	−0.031	0.035	−0.010	0.12***
2[a,d]	(0.03)	(0.03)	(0.10)	(0.16)	(0.03)	(0.03)	(0.12)	(0.19)	(0.05)	(0.05)	(0.16)	(0.03)
Consumption quintile	−0.16***	0.15***	0.10	0.69***	−0.16***	0.14***	0.18*	0.56***	−0.16***	0.16***	−0.061	0.96***
3[a,d]	(0.03)	(0.03)	(0.09)	(0.16)	(0.03)	(0.03)	(0.11)	(0.17)	(0.05)	(0.05)	(0.15)	(0.05)
Consumption quintile	−0.22***	0.16***	0.27***	0.78***	−0.23***	0.15***	0.40***	0.69***	−0.20***	0.16***	0.039	0.98***
4[a,d]	(0.03)	(0.03)	(0.09)	(0.17)	(0.03)	(0.03)	(0.11)	(0.20)	(0.05)	(0.05)	(0.16)	(0.03)
Consumption quintile	−0.24***	0.14***	0.41***	0.93***	−0.26***	0.15***	0.52***	0.89***	−0.17***	0.11*	0.16	0.94***
5[a,d]	(0.03)	(0.03)	(0.10)	(0.18)	(0.04)	(0.04)	(0.12)	(0.21)	(0.06)	(0.06)	(0.17)	(0.03)
Location												
Rural household	0.24***	−0.14***	−0.32***	−0.023	0.25***	−0.16***	−0.25***	−0.031	0.22***	−0.10***	−0.43***	−0.037
	(0.02)	(0.02)	(0.05)	(0.08)	(0.02)	(0.02)	(0.06)	(0.10)	(0.03)	(0.03)	(0.09)	(0.04)

Continued.

Table 7. *Continued.*

Data Segment	75%				50%				25%			
Dependent variable: Energy sources	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**
Gender and wealth												
Female-headed household × consumption quintile 2	0.11* (0.06)	−0.11* (0.07)	0.013 (0.24)	−0.21 (0.36)	0.17** (0.08)	−0.15* (0.08)	−0.060 (0.30)	−0.28 (0.45)	0.056 (0.11)	−0.079 (0.12)	0.12 (0.42)	3.36*** (0.05)
Female-headed household × consumption quintile 3	0.033 (0.07)	−0.056 (0.07)	−0.076 (0.26)	−0.68* (0.41)	0.093 (0.08)	−0.11 (0.07)	0.13 (0.30)	−3.84 (3.00)	−0.059 (0.14)	0.013 (0.12)	−0.62 (0.43)	2.72*** (0.05)
Female-headed household × consumption quintile 4	0.10* (0.06)	−0.078 (0.06)	−0.20 (0.26)	−0.075 (0.37)	0.19*** (0.07)	−0.14** (0.07)	−0.22 (0.30)	0.078 (0.45)	−0.048 (0.10)	0.023 (0.11)	−0.15 (0.44)	2.89*** (0.06)
Female-headed household × consumption quintile 5	0.12** (0.06)	−0.075 (0.06)	−0.18 (0.24)	−0.57* (0.34)	0.15** (0.07)	−0.097 (0.07)	−0.15 (0.28)	−0.54 (0.37)	0.071 (0.11)	−0.028 (0.11)	−0.28 (0.42)	2.56*** (0.04)
Region												
Region 2 (Manatuto, Manufahi, Ainaro)[a,f]	0.38*** (0.03)	−0.34*** (0.03)	−0.14** (0.07)	−0.036 (0.17)	0.37*** (0.03)	−0.36*** (0.03)	−0.085 (0.09)	−0.15 (0.22)	0.39*** (0.05)	−0.27*** (0.05)	−0.28** (0.12)	0.086** (0.04)
Region 3 (Dili, Aileu, Ermera)[a,f]	0.24*** (0.03)	−0.11*** (0.02)	−0.61*** (0.07)	−0.36** (0.15)	0.23*** (0.03)	−0.10*** (0.03)	−0.65*** (0.08)	−0.37** (0.17)	0.25*** (0.05)	−0.099** (0.04)	−0.56*** (0.11)	−0.39*** (0.05)
Region 4 (Bobonaro, Cova Lima, Liquiçá)[a,f]	0.28*** (0.03)	−0.14*** (0.02)	−0.40*** (0.07)	−0.079 (0.15)	0.28*** (0.03)	−0.14*** (0.03)	−0.48*** (0.09)	−0.010 (0.17)	0.28*** (0.04)	−0.14*** (0.04)	−0.28** (0.12)	−0.28*** (0.05)
Region 5 (Oecusse)[a,f]	0.11*** (0.02)	0.077*** (0.02)	−0.71*** (0.06)	0.91*** (0.10)	0.080*** (0.03)	0.092*** (0.03)	−0.68*** (0.07)	0.92*** (0.12)	0.14*** (0.04)	0.074** (0.04)	−0.80*** (0.10)	0.86*** (0.03)
Constant	0.17* (0.10)	0.80*** (0.09)	−1.92*** (0.33)	−3.36*** (0.64)	0.16 (0.12)	0.87*** (0.11)	−2.40*** (0.41)	−3.55*** (0.76)	0.16 (0.17)	0.66*** (0.16)	−0.99* (0.53)	−2.83*** (0.05)
Sigma	0.34*** (0.01)	0.33*** (0.01)	0.76*** (0.03)	0.72*** (0.07)	0.34*** (0.01)	0.33*** (0.01)	0.77*** (0.04)	0.72*** (0.08)	0.35*** (0.01)	0.32*** (0.01)	0.72*** (0.05)	0.68*** (0.02)

Continued.

Table 7. *Continued.*

Data Segment	75%				50%				25%			
Dependent variable: Energy sources	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**	**Kerosene**	**Fuelwood**	**Electricity**	**Other Fuels**
No. of observations	3,267	3,267	3,267	3,267	2,178	2,178	2,178	2,178	1,089	1,089	1,089	1,089
Left-censored observations	830	467	2,492	3,102	537	320	1,666	2,070	293	147	826	1,032
Uncensored observations	2,437	2,280	775	165	1,641	1,858	512	108	796	924	263	57
Right-censored observations	0	0	0	0	0	0	0	0	0	0	0	0
Pseudo R^2	0.23	0.18	0.11	0.24	0.24	0.19	0.13	0.24	0.24	0.16	0.11	0.30
Log pseudolikelihood	−64,999.91	−60,081.08	−57,399.60	−13,245.91	−42,546.44	−40,162.23	−37,289.00	−8,909.91	−21,837.43	−19,138.43	−19,360.31	−3,996.55

[a]Dummy variables
[b]Excluded category: male-headed households
[c]Excluded category: household head with no education
[d]Excluded category: consumption quintile 1
[e]Excluded category: urban households
[f]Excluded region: Region I: (Baucau, Lautém, Viqueque)
Notes: Robust standard errors in parentheses. *** = 1% level of significance, ** = 5% level of significance, * = 10% level of significance.
Source: Authors' calculations.

The first segment of Table 6, which includes 75% of total sampled households, clearly supports both of our hypotheses (1 and 2) that relatively affluent households are less likely to choose kerosene and more likely to choose wood and electricity as their sources of energy for domestic use. The middle segment, which includes 50% of total sampled households, and the last segment, which includes only 25% of total sampled households, also both support hypothesis (1). The estimated functions in Table 6 confirm that households progressively choose clean energy such as electricity as the level of education of the household head rises. The results in Table 6 are similar to those in Table 4 with respect to both the sign and the size of the coefficients. Even the influence of other variables such as the coefficient of the rural household dummy behaves the same during sensitivity tests as in the original estimation shown in Table 4.

In Table 7, we presented estimated functions applying a Tobit model to explain household expenditure shares on different energy sources. Similar to Table 5, we estimated the function first using 75% of total sampled households, and subsequently by using 50% and 25% of total sampled households. In each segment, the estimated results clearly show that household heads with higher levels of education spend relatively less on kerosene and wood and significantly more on cleaner energy such as electricity. Table 7 also demonstrates that relatively affluent households spend less on kerosene and more on electricity. The sensitivity analyses in Tables 6 and 7 support hypotheses (1) and (2); that is, more educated and affluent households, respectively, are more likely to use and spend more on electricity than other energy sources such as kerosene. In Tables 6 and 7, the observed behavior of relatively rich and female-headed households in choosing fuel sources and their relative dependency in terms of expenditure allocated to these fuel sources is consistent across the estimated functions using different data segments. These findings are also consistent with our observations from Tables 4 and 5.

Finally, the regional dummies are consistent across the estimated functions for different data segments in Tables 6 and 7, which is similar to our observations from Tables 4 and 5, indicating the robustness of the findings in these tables.

V. Conclusions and Policy Recommendations

This study uses data from the TLSLS 2007 to analyze household energy choices and dependency. In Timor-Leste, a significant proportion of the population use kerosene and fuelwood, while a smaller number of households use electricity. We found that only about 23% of total sampled households use electricity. Access to electricity among rural households is particularly limited. Only about 12% of sampled rural households were connected to the electric grid in 2007, compared with about 37% of sampled urban households.

Applying a multivariate probit model, this paper first explains the factors that affect the energy choices of households in Timor-Leste. Econometric results reveal that household characteristics such as the sex of the household head, the number of family members, the level of education of the household head, and income play an important role in the choice to use clean energy such as electricity. Our findings show that with an increase in the level of education of the household head, the probability of using electricity, which is a clean energy compared with kerosene and other fuel sources, increases progressively and the probability of using kerosene and fuelwood decreases progressively. Household wealth also affects energy choices as wealthier households are more likely to use clean energy and relatively poorer households are more likely to use kerosene.

The Tobit model, which identifies household dependency on a particular source of energy by measuring a household's share of expenditure on it, also confirms that household heads with higher levels of education spend relatively more on electricity and less on kerosene, reflecting a greater dependency on clean energy. The Tobit estimation confirms that wealthier households are also more dependent on electricity; in contrast, poorer households are more dependent on kerosene. Due to a lack of access to electricity, rural households are less likely to use electricity and more likely to use kerosene and fuelwood. Our econometric results confirm the impact of females on energy choices as female-headed households are more likely to use fuelwood and spend a larger share of household energy expenditure on it. The opportunity cost of fuelwood collection, a burden which generally falls upon female household members, increases as female incomes rise. Therefore, income-generating activities targeting poor and rural females can reduce the use of and dependence on fuelwood. Furthermore, rural electrification efforts need to be expanded to ease barriers to access to clean energy, which implies a potentially significant role for donor agencies.

This study clearly demonstrates that as income and education levels increase households are more likely to opt for clean energy, as predicted by the energy ladder hypothesis. While markets can play a role in facilitating economic growth and meeting the demands of burgeoning populations in developing economies, international donor agencies should also work with domestic governments to ensure that an adequate supply of clean energy is available for all at affordable prices. This may not be an easy task given the current economic situation of many developing economies like Timor-Leste. Generating affordable electricity for all by supplying natural gas to households in a developing economy, for example, requires major long-term investments. The increased use of more energy-efficient fuelwood stoves or solar-based stoves are alternative options that could help households achieve a stepwise transition toward reliance upon more sustainable energy sources. Governments and nongovernmental organizations can raise environmental and public health awareness and supply such stoves at affordable prices with the help of international donor agencies.

International donor agencies should also invest in raising education levels in developing economies. As educated household heads are more aware of the negative impacts of the use of kerosene and fuelwood, enhancing education systems in resource-poor developing economies can reduce the number of people suffering the negative consequences of using biomass and other dirty energy sources. Furthermore, a reduction in the use of biomass as a fuel can also bring enormous positive improvements to soil health and the environment.

While this study demonstrates the relationship between income, human capital (education), and energy choices, such choices can also be influenced by other factors such as consistency in the supply of electricity, energy prices, and the types of food and cooking practices that are part of the local culture. A household's dependency on cleaner sources of energy such as electricity may not necessarily be the result of relatively higher purchasing power, but rather because of factors such as the price and availability of electricity. Future studies should focus on these issues in examining household energy choices in developing economies.

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*ADB recognizes "China" as the People's Republic of China and "Hong Kong" as Hong Kong, China.

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