Urban Energy Transition and Technology Adoption: the Case of Tigrai, Northern Ethiopia

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Abstract

Urban centers have long been dependent on the rural hinterlands for about 90% of their fuel needs in Ethiopia. Whereas dependence of urban centers on rural hinterlands is one of the causes of deforestation, the later in return has resulted in growing fuel scarcity and higher firewood prices. One response to reducing the pressure of urban centers on their rural hinterlands could be switching from one fuel source to another, known as energy transition. Switching from fuelwood to electricity, for instance, leads to reduced pressure on the forest resources and lower indoor air pollution. However, such a transition is conditioned by the adoption of the relevant cooking appliance or stove technology by the majority users. This paper tried to investigate urban energy transition and technology adoption conditions using a dataset of 350 urban households in Tigrai, northern Ethiopia. Results suggest that the transition to electricity is conditioned by holding electric '*mitad*' cooking appliance, which is in turn influenced by the level of education and income, among other things.

Keywords: urban energy transition; probit regressions; electric '*Mitad*' cooking appliance/ technology adoption; Tigrai; Ethiopia.

JEL *classification*: Q4; Q41; Q48

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1. Introduction

Urban centers have long been dependent on rural hinterlands for their fuel (Barnes et al., 2004). For example, in Ethiopia, Wright and Yeshinigus (1984) report that woodlands around Axum were cut down to supply fuel for the growing population of city dwellers, at the time of Axumite civilization. The Axumite civilization was undergoing during ancient civilizations in the Middle East and Greece spanning from around 1000 B.C. to 1st millennium A.D. (Butzer, 1981; Phillipson, 2000). This long history of dependence of urban centers on their rural hinterlands has aggravated the level of deforestation, on the one hand. On the other hand, the deforestation has resulted in growing fuel scarcity and higher firewood prices in urban centers (Gebreegziabher, 2007). The environmental impact of urban fuel demand in general and the reliance on biofuels in particular, in terms of contributing to forest degradation, is well established (Heltberg, 2004; Edwards and Langpap, 2005). This impact is much more serious in the environments with very limited wood resources such as the African Sahel (Morgan, 1983; Kramer, 2002; Kramer, 2004). Even if the levels of per capita consumption of fuelwood is low, the concentration of a large number of people in smaller areas like cities and towns coupled with the preference of urban households for charcoal over wood intensify the pressure on the existing local forest resources.

The fundamental question is as to how could the pressure of urban centers on the rural hinterlands for energy source be reduced? One response to reducing the pressure of urban centers on their rural hinterlands could be through energy transition from one source of fuel to another. Substituting away or switching from fuelwood to electricity is one example of such a transition. Electricity is one source of energy for cooking and it is cleaner and does not cause for deforestation. Hence, switching from fuelwood to electricity leads to reduced pressure on the forest resources and lower indoor air pollution. However, such a transition is conditioned by the adoption rate of the relevant cooking appliance or stove technology. In other words, it requires the majority of the households adopt the innovation. Hence, it becomes very crucial to understand the factors that determine the adoption rate.

This paper tries to investigate urban energy transition and technology adoption as the possible means of reducing the pressure of urban centers on the rural hinterlands. The study uses a dataset of 350 urban households from stratified samples of seven urban centers in

Tigrai, Northern Ethiopia for the year 2003. More specifically, the paper aims at (1) assessing the electric (*mitad)* cooking appliance holding or adoption rate and how it conditions urban energy transition, and (2) analyzing factors explaining fuel choice of urban households' for the various fuels.

The remaining part of the paper is organized as follows. In section 2, the paper briefly reviews fuel use, urban energy transition and deforestation. Section 3 presents the model for fuel demand and the implication, using comparative statistics. Section 4 provides the empirical model and describes the nature of the data. Section 5 presents results and discussions. Section 6 concludes.

2. Fuel Use, Urban Energy Transition and Deforestation: A Review

Much of the previous studies (cf. Amacher et al. 1993 and 1996; Heltberg, Arndt and Sekhar, 2000; Kohlin and Parks, 2001) have emphasized on the rural-side and little has been done with respect urban dimension of the fuel problem. Using a data from Guatemalan households, Edwards and Langpap (2005) analyzed startup costs and the decision to switch from firewood to gas fuel. Except for the magnitude of these effects were small upon simulation, their results indicated that access to credit, through its effect on the ability of the household to finance the purchase of a gas stove, plays a significant role determining the quantity of wood consumed by Guatemalan households. That startup costs in terms of the purchase of gas stove could be significant impediment to the adoption of liquefied petroleum gas (LPG) as an alternative to wood. They also saw subsidizing stoves as a more promising policy option for reducing firewood consumption as well as the pressure on local forests. Using a large household consumption survey data, Pitt (1985) examined at the empirical basis for both the deforestation and equity arguments of kerosene subsidy in Indonesia. Pitt concluded the there was no evidence in support of the deforestation argument for kerosene subsidy. Moreover, Pitt also concluded that the total kerosene subsidy is disproportionately captured by the non-poor and that the equity argument for kerosene subsidy cannot be strong.

In addition, Kebede et al. (2002), Chambwera (2004), Heltberg (2004) are among the few other previous studies in this respect. Using comparable household survey data from six developing countries, Heltberg (2004) analyzed the determinants of household fuel use and fuel switching. Main findings include (i) per capita expenditure positively relates to modern fuel use whereas it related negatively to solid fuels; (ii) electrification of the household enhances modern fuel uses while it decreases usage of solid fuels; (iii) use of more number (mix) of fuels, both solid and non-solid, is related with larger family size; (iv) higher levels of education are associated with a greater probability of the household using modern fuels and a lower probability of using solid fuels; and (v) availability of a tap water inside the house enhances fuel switching. He did not see that many policy options for promotion of fuel switching. However, did see that, particularly in urban areas, the general economic development bringing income growth would in itself to some extent help trigger fuel switching. Using data from Harare, Zimbabwe, Chambwera (2004) analyzed urban fuelwood demand and factors explain differences in energy consumption pattern between electrified and un-electrified households. He found that whereas energy expenditure pattern of electrified households are, among others, affected by household characteristics such as income, household size, the number of rooms used by the household, and the education level of the head; the energy expenditure pattern of un-electrified household was less affected by these characteristics. Kebede et al. (2002) examined domestic energy demand pattern of ten large cities and towns in Ethiopia. They concluded that urban specific factors other than income (such as fuel availability and climate) appear to be very important in determining demand for modern energy.

In their synthesis of woodfuels, livelihoods and policy interventions, Arnold *et al*. (2006) argue that the fuelwood discourse or crisis has shown a classic pattern of thesis and antithesis over the last few decades. That the use of fuelwood in developing countries is apparently not growing at the rates assumed in the past. Nonetheless, they also acknowledge that the complex reality in developing countries could seldom be captured in such a clear-cut narratives. For example, it might not he the case for Ethiopia, hence the need for location or country specific studies. Regarding the impact of urbanization on consumption, they emphasized that total consumption of woodfuels in much of urban Asia has been declining or growing only slowly, with shifts to other fuels, as income and city size increases. Whereas Africa is characterized by strong growth in urban consumption of woodfuels, mainly as charcoal instead of as fuelwood, owing to persistently low incomes.

Barnes et al. (2004) see that urbanization is also a process of fundamental transformation in human behavior and not merely an increase in population density. They argue that the pattern of the relationship between urbanization, fuel choice, and household energy consumption involve dynamic processes and complex set of feedbacks. They also argue that such complexities give rise to diverse possibilities of transitional pathways in modernizing energy markets. At their earliest stages of urbanization or cities’ development where wood is extensively available, urban residents typically consume woodfuel to the exclusion of other fuels. This could be because traditional fuels can be supplied relatively economically or as a side-effect of agricultural land conversion. As urban areas expand however, the incentive to consume biofuels will be moderated by a number of feedback effects. For example, they argue that diminishing biomass resources in the vicinity of cities would increase the harvest and transport costs of woodfuels as urbanization proceeds. They argue that, eventually, as urban areas expand, modern fuels will become more available and affordable by way of well established networks. In this respect, rising incomes and rapid urbanization are seen as the crucial variables or drivers of the transition. They also argue that it matters whether the rising incomes are equitably distributed or not in terms of the urban energy transition being broadly-based or abrupt.

The following conclusions can be drawn from the foregoing review. Firstly, much of the previous studies (cf. Amacher et al. 1993 and 1996; Mekonen, 1999; Heltberg, Arndt and Sekhar, 2000; Kohlin and Parks, 2001) have emphasized on the rural-side and little has been done with respect urban dimension of the fuel problem. Secondly, even among the few other previous studies in this respect (cf. Kebede et al. (2002), Chambwera (2004), Heltberg (2004)) that also considered the urban dimension the focus has been on whether the poor can afford modern fuel (Kebede et al., 2002), instead of broader policy questions and the diverse potentialities there in to tackle the problem. Thirdly, the transition from traditional to modern fuels has often been conceptualized, in the literature, as a relatively straightforward three-stage process (Barnes et al., 2004). Woodfuel is the predominant energy source in stage one. Stage two is marked by local deforestation manifested in terms of a decrease in wood availability and the emergence of markets for charcoal and kerosene. Stage three is characterized by developed markets, rising incomes, and large scale fuel switching to LPG and electricity. However, the argument is that the transition might not be that simple and that the extent of the environmental and health effects (positive externalities) generated thereof is conditioned by technology adoption. Moreover, knowledge about the characteristic, particularly empirical evidences on the behavioral factors underlying cooking appliance or stove technology holding (adoption) is sparse if not non-existent.

3. Theoretical Model

In this section, we specify a theoretical utility maximization model and the demand for electricity consistent with discrete appliance choice, following Dubin and McFadden (1984). Emphasis has been given to electricity demand and the use of electric *mitad* cooking appliance because electricity is a substitute, for fuelwood as far as baking *injera* is considered. But, more importantly, Ethiopia is also one of the few African countries with an immense potential for producing hydro power and significant breakthroughs could be brought about, both in terms reducing the pressure on local forests and gaining positive environmental/health externalities, through transition from fuelwood to electricity.

Economic theory suggests that the demand for owning consumer durables arises from the flow of their services. The utility associated with a consumer durable is at best observed indirectly. Although durables may differ in capacity, efficiency, versatility, and of course the corresponding prices, the consumer will ultimately utilize the appliance at an intensity level that provides the 'necessary' service. Corresponding to this usage will be the cost of the derived demand for the fuel that the durable consumes. The consumer must weigh each alternative appliance against expectations of future use, future energy prices and current financing decisions in view of maximizing her utility.

Consider a consumer who faces a choice of *m* mutually exclusive, exhaustive cooking appliance portfolios, which can be indexed as i= 1, …, *m*. Appliance portfolio *i* has a rental price r_i. Given appliance portfolio *i*, the consumer has a conditional indirect utility function (Dubin and McFadden, 1984):

(1) $$u = V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta)$$

where p_1 is price of electricity, p_2 is price of alternative energy source (i.e., fuelwood), y is income, z_i is observed attributes of appliance portfolio *i*, $\in_i$ is unobserved attributes of portfolio *i*, r_i is price (cost) of appliance portfolio *i*, η is unobserved characteristics of the consumer. Using Roy's identity (Mascolell et al., 1995), electricity and alternative energy (fuelwood) consumption levels, given appliance portfolio *i*, are given by:

(2) $$x_1 = \frac{-\partial V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta)/\partial p_1}{\partial V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta)/\partial y}$$

(3) $$x_2 = \frac{-\partial V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta)/\partial p_2}{\partial V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta)/\partial y}$$

Hence, the probability that appliance portfolio *i* is chosen is given by:

(4) $$\begin{aligned} P_i = \Pr ob\{(\in_1, ..., \in_m, \eta) : V(i, y - r_i, p_1, p_2, z_i, \in_i, \eta) \\ > V(j, y - r_j, p_1, p_2, z_j, \in_j, \eta) \text{ for } j \neq i\} \end{aligned}$$

Once the function *V* satisfies the necessary and sufficient conditions/properties of an indirect utility function, it can be used to construct the econometric model.

4. Empirical Model, Study Area and Data

4.1 Empirical model

The empirical framework specifies a discrete choice model. Therefore, the paper focuses on the adoption of fuel efficient cooking appliance in general and the electric *mitad* stove in particular and the behavioral factors that underline the adoption. Let S be an indicator variable indexing whether the household owns an electric *mitad* cooking appliance (stove) ($S=1$) or not ($S=0$). Hence, the probit model of electric *mitad* cooking appliance adoption can be specified as:

(5) $\text{prob } (S_i=1) = \Phi(x_i'\beta)$

where Φ is the standard normal distribution function, x_i a vector of regressors and β is a vector of parameters to be estimated. Equation 5 also implies that prob ($S_i = 0$) = $1-\Phi(x_i'\beta)$.

4.2 Sampling and data description

A one period data was collected from a stratified sample of three hundred fifty urban households. The 1994 Population and Housing Census (CSA, 1995) identifies 74 towns in Tigrai. These urban centers could be stratified into four topologies: city, large, medium, and small towns based on population size (Table 1). Two stage sampling technique have been applied in selecting the sample households. First sample towns were selected and then sample households were selected from the sample towns in such a way that every household have had the same chance of being included in the sample. However, the choice of focal towns was not random. This procedure helps not to select a town at the western tip of the region, which might have been unaffordable given the time and budget limitations.

To have an idea of the current population and base the sampling on the population size, the population of the focal towns was projected for 2000 and 2003. Proportionate sampling based on the share of towns from the current population was applied. The details about sample towns and sample size by town are provided in Table 2.

Questionnaire was prepared and used for data collection. Data pertaining to food and non-food non-fuel expenditure, expenditure on the different fuel sources (firewood, charcoal, kerosene, electricity, etc), income, and types of cooking appliance (stove) technologies used were collected. In addition, information on fuel preferences, reason for not using specific cooking appliance or stove type, etc was also collected. Five enumerators were trained and used for the data collection. Summary statistics of the variables considered in the analysis is provided in Table 3. Although the questionnaire was designed to collect data on all possible fuel types and categories, none of the sample households were found to use LPG and crop residues. In addition, only about 20 percent of households were found using dung which is freely collected. Thus, the empirical analysis focuses on the four fuel goods: firewood, charcoal, kerosene, and electricity. In general, expenditure on these fuels accounts for about 19 percent of household's total budget.

Table 4 relates city/town size (population) and income with energy use both in terms of per capita fuel consumption per year in KgOE, i.e., kilogram of oil equivalent, as well as fuel choice in percentage terms. Data suggests per capita fuelwood consumption is the largest among households that do not use electricity or in areas where electricity is not available. Per capita kerosene consumption was found to be largest in Mekelle and Adigrat whereas per capital electricity consumption was largest in Mekelle and Wukro. However, the data do not show any clear pattern be it in terms of increasing urbanization (as explained by city/town size) or rising income per capita vis-as-vis fuel consumption, energy tansition.

4.3 Description of study area

Tigrai is the most northern region of Ethiopia. Traditional biofuels are the dominant source of fuel for the great majority of the urban population in the area. Appendix Table A.1 presents energy consumption pattern of urban households in Ethiopia both for the overall country in general and Tigrai region in particular. In Tigrai, in 1995, biofuels accounted for over 90 of fuel consumption of urban households. However, the share of traditional fuels declined by about 6 percent whereas electricity consumption has increased from 0.8 percent in 1995 to 5.8 percent in 2003 in urban areas of Tigrai.

Baking *injera* and cooking sauce, soup or stew (*wet*) from meat, vegetables or other items are the two most important activities accounting for the bulk of urban domestic fuel consumption in Ethiopia. Boiling water, making coffee and similar other activities also involve lighting a fire several times a day. In all settlement typologies i*njera* baking is the major consumer of fuel wood and accounts for about 60 percent of the total household fuel consumption (Gebreegziabher, 2004 and RTPC, 1998).

Electricity and petroleum products are the two modern fuel sources in the case of Ethiopia. Among the petroleum products, kerosene and LPG are important sources of light and power in both urban and rural areas. In cities and large towns, kerosene is used for cooking by many households. In medium and small towns, where there is no electricity supply, kerosene is most often used for lighting. In rare cases, it is also used for cooking.

With regards to electricity, Ethiopian Electric Power Corporation (EEPCo) is the major supplier. There are also few community and privately owned systems. There are two power supply systems in the country, the interconnected system (ICS), which has grid connections and is mainly supplied from hydropower plants, and the self contained system (SCS), which constitutes isolated power generating units operating with diesel. Table A.2 in the Appendices, shows the role of these two systems in the overall electricity/power supply of the country. Electricity supply has considerably improved during the past few years. For example, overall electricity supply increased by 37 percent in the last five years (Appendix A.2) with the main growth coming from the expansion of hydro power supply. On the users side, EEPCo has about 800 thousand customers throughout the country, ranging from domestic users to high voltage large industries. Electricity constitutes less than 4 percent in the total domestic consumption of urban households and the current level of electrification is only about 14 percent (ADC, 2003). By and large, lighting is the dominant end use in the domestic sector and the use of electricity for cooking is limited to very few households in larger towns. This also implies a persistent increase in the demand for fuel wood and growing pressure on local forests.

5. Results and Discussion

5.1 Cooking appliances/ injera baking stove in Tigrai

The clay enclosed traditional *Tigrai* type stove was found to be the predominant stove used in urban areas. Open hearth (three-stone stove), *Tehesh*, *Mirte* and the electric *mitad injera* baking stoves were also found to be used by sample households. These cooking appliances or stove technologies used in baking *injera* in urban areas could be categorized into two: wood stoves and electric *Mitad* stoves. With the exception of the electric *mitad* all the rest are essentially wood stoves. A description of the different cooking appliances or stove holdings (used) by sample households is provided in Table 5.

Open hearth (three-stone stove) was found to be rarely used except in some local beer breweries. In addition, the *Tehesh* and *Mirte* stoves were found in the hands of limited number of households. The open hearth (three-stone stove) has a very low efficiency and about 85 to 90 percent of the potential energy is wasted (Dunkerley et al., 1981; Gebreegziabher, 2007), which implies an increased demand for traditional or biofuels and hence an increased pressure on local forests. Both *Tehesh* and *Mirte* are improved stoves recently introduced in light of the growing fuel problem. *Tehesh* is different from the traditional *Tigrai* type stove in that it is a double-walled stove with a baffle that permits smoke (and heat) to recycle before it escapes out of the chimney. It has also an insulation from the bottom. The use of *Tehesh* stove is assumed to allow about 22 percent of fuel savings as compared to the *Tigrai* variants that have only a single wall. The *Mirte* stove is the most recent technology in stove R&D. It is a pumice-cement stove, which is portable and easy to assemble . Others things being constant, adoption of improved wood stove with conversion efficiency of say 20 to 30 percent could reduce fuel wood consumption of the household by 50 percent as compared to the traditional one.

Despite most sample households, about 80 percent, were using electricity, only about 20 percent were found to have adopted the electric *mitad* cooking appliance. The expensiveness of the stove was the main reason for non-adoption. For example, two-thirds of the non-adopters responded that it is too expensive.

5.2 Electric 'mitad' cooking appliance holding (adoption)

Electricity is mainly used for lighting among sample households and wood or trees still constitute the major source of fuel. Had all households adopted electric *mitad* stove, the fuel wood that would have been consumed could have been substantially saved.

A Probit model (equation (5)) was estimated to determine the factors underlying the adoption of the electric *mitad* cooking appliance. Price of related goods, household income (expenditure), and other household characteristics including family size, age and education of the head were the explanatory variables considered. Results are presented in Table 6. All price variables turned out to be insignificant. This was contrary to what is expected and against the main reason mentioned by households themselves for not using electric cooking appliance. However, it appears that price of related good affects household's decision to consume electricity. Characteristics of household such as household income (expenditure), family size, age and education are positive and significant, and matter more in determining whether or not household adopts the electric *mitad*. As could be clear from Table 6, overall validity of model is also quite good. Considering likelihood ratio (LR) test, for example, computed value chi-square was greater than the critical value at far better than 1 percent level of significanc. This implies that the restrictions do not apply. Or put differently, this was in favor of the alternative hypothesis that all of the explanatory variables included help explain the variation. Also provided in the table are marginal effects of the variables on the probability of electric *mitad* adoption. According to the result, an increase in the household income increases the likelihood of adopting electric *mitad*. One year of extra schooling of the household head *ceteris paribus* increases the probability of adoption by 0.031. Similarly, holding all others things constant, a unit change in family size and age also implied an increase in probability of adoption by 0.028 and 0.010 respectively.

5.3 Factors affecting fuel choice

A Probit model is estimated to identify factors explaining household's fuel choices. It gives insights about how the different sources of fuel goods considered are related to each other. Results are presented in Table 7.

Price of related good, household income (expenditure) and other household characteristics such as employment type or occupation were the explanatory variables considered in the empirical analysis. Whereas the rest of the variables were found to be insignificant, education of the head of the household significantly and negatively influenced the decision to consume wood. Price of kerosene positively and significantly influenced the decision to consume charcoal. Moreover, household income, family size and age significantly influenced the decision to consume charcoal. Education of the head of the household significantly and negatively influenced the decision to consume wood. Results indicate that an increase in the level of education of the head of the household by one unit, for instance, say from lower primary (grade 1-3) to higher primary (grade 4-6) schooling, would on average reduce the probability of households to consume wood by 16.5 percent, ceteris paribus. This implies that the higher the level of education, the less likely will be the household to consume wood.

A positive association of the price of kerosene and the decision to consume charcoal also suggests that charcoal and kerosene are substitutes. Similarly, price of charcoal positively and significantly influenced the decision to consume kerosene.. In addition, household income and age were found to be statistically significant. Price of wood, price of charcoal, age and education of head turned were found to be significant and positive as far as the decision to consume electricity in concerned. The positive relation between price of wood and household's decision to consume electricity indicates that wood and electricity are close substitutes.

Arnold et al. (2006) argued that charcoal remains to be a major source for the urban poor, implying charcoal to be a perfect and only substitute for fuelwood. However, results in this paper reveal that charcoal and kerosene are substitutes and that wood and electricity are also interchangeably used. Moreover, findings in this paper portray the diversity of lifestyles[1] and end-uses or purposes for which these fuels are used in the different local circumstances. For example, in countries like Ethiopia where *injera* baking and cooking stew and similar food items are the two typical end uses as far as urban domestic energy consumption is considered, fuelwood is mainly used for *injera* baking while charcoal is mainly used for the other purpose. The cooking appliances or stove technologies are also quite different which inhibits the ease of substitution.

6. Conclusions

This paper investigated urban energy transition and new technology adoption as a way of reducing the pressure of urban centers on the rural hinterlands. A Probit model was estimated to determine the factor underlying the use of electric *mitad* cooking appliance Factors explaining household's choice for specific fuel good was also estimated using the Probit model. The following important conclusions can be drawn from the foregoing discussion.

Besides prices of related goods, household income (expenditure) and other household characteristics such as family size, age and education of head of households are important variables explaining household's choice of a particular fuel. Nonetheless, the relative importance of factors varied from one fuel source to the other. It doesn't make a difference in terms of fuel source selection whether the household head is self employed or a public or private employee. Improvement in income and education enhance the likelihood of the household to increase consumption of electricity and reduce consumption of wood, implying a reduction in the pressure on wood resources. Moreover, Probit regression results on household's fuel choice suggest that charcoal and kerosene as well as wood and electricity are substitutes.

The results in this paper also help to draw the following implications. Raising the level of education and income of households will enhance the use of electricity and electric *'Mitad'* adoption and urban energy transition. On the other side, enhancing education levels of households tends to reduce the level of wood consumption. Thus, policy interventions in this regard would help to facilitate the energy transition from fuel wood to electricity through

[1] The term *lifestyle,* in here, is used to mean how people (individuals or in group) live, how they cook including their food habits.

widespread use of more efficient cooking appliances and thus reduces the pressure of urban centers on their rural hinterlands and the resulting deforestation.

It is also important to help disseminating improved wood stoves such as *Tehesh* and *Mirte* in the short-run and electric *mitad* cooking appliance in the medium and long run so as to improve efficiency in the use of fuel wood and consequently fully switching from fuelwood to electricity over time.

Evidences in this paper also suggest a growing role of modern fuels such as electricity and kerosene and a declining role of dung and charcoal, particularly in urban areas, however, do not support for the *energy ladder* hypothesis. This could be because Ethiopia is at the bottom of the energy ladder.

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Table 1 Criterion for classification of urban center(s) into settlement typologies

Settlement typology	Criterion (population or number of inhabitants)
City	$> 100\times10^3$
Large town	$25 - 100\times10^3$
Medium town	$5 - 25\times10^3$
Small town	$< 5\times10^3$

Source: EESRC (1995)

Table 2 Description of Sample towns and sample size by town

Town		Population 2003 (Projected)				Total	
		Both Sexes	Male	Female	% of Total	Total Sample	Sample size/ town
	(1)	(2)	(3)	(4)	(5)	(6)	(7)=(5)*(6)
Mekelle	City	139292	65709	73583	0.558	300	167
Adigrat	Large town	53765	24933	28832	0.216	300	65
Wukro	Medium town	23596	10672	12924	0.095	300	28
Kuha	Medium town	14178	6230	7948	0.057	300	17
Adigudem	Medium town	9798	4450	5348	0.039	300	12
Hagereselam	Medium town	5704	2308	3396	0.023	300	7
Samre	Small town	3072	1338	1734	0.012	300	4
Total		249405			1.00		300

Table 3 Summary statistics of variables considered in the analysis (n=350), year 2003

Variable	mean	Std. Dev.	Min	Max
Family size	4.925	2.196	1	10
Age of head	49	14	18	95
Education of head/ highest grade completed				
Illiterate (in percent)	39			
Grade 1-3	15			
Grade 4-6	18			
Grade 7-8	11			
Grade 9-11	5			
Grade 12 and above	12			
Employment type/occupation of head				
Self employed (in percent)	69			
Public employee	16			
Private employee	15			
Wood price (Birr/kg)[a]	0.47	0.259	0.05	3.00
Charcoal price (Birr/kg)	0.64	0.299	0.08	1.67
Kerosene price (Birr/lit)	2.36	0.389	1.00	5.00
Electricity price (Birr/kWh)	0.28	0.206	0.01	3.66
Total expenditure (in Birr)	6,910	5,087	1,045	46,398
Budget share of fuel	0.206	0.080	0.018	0.469
Budget share of food	0.620	0.112	0.085	0.875
Budget share of other goods and services	0.174	0.117	0	0.878
Budget share of wood	0.105	0.075	0	0.403
Budget share of charcoal	0.035	0.033	0	0.193
Budget share of kerosene	0.021	0.020	0	0.128
Budget share of electricity	0.030	0.030	0	0.196

[a] Birr is Ethiopian currency currently 1USD = 10.8680 Birr

Table 4 City/town size and fuel use in seven urban centers in Tigrai, 2003[a]

City/town	Population (000)	Annual income (ETB/cap)	Fuel			
			Fuelwood	Charcoal	Kerosene	Electricity
			Fuel consumption (KgOE per capita per year)[b]			
Mekelle	139	1778.04	536.96	463.27	72.17	128.96
Adigrat	54	1391.12	198.04	165.45	69.07	50.08
Wukro	24	1500.56	131.64	219.08	47.53	122.39
Kuha	14	1576.50	604.12	349.47	23.69	65.25
Adigudem	10	1205.15	498.20	531.26	2.61	24.96
Samre	6	1412.52	906.91	237.94	19.59	0
Hagereselam	3	1358.52	921.20	296.72	41.17	0
			Fuel choice (percentage)			
Mekelle	139	1778.04	85.95	76.03	61.16	98.35
Adigrat	54	1391.12	96.77	80.64	97.85	100.00
Wukro	24	1500.56	93.75	87.50	65.62	96.87
Kuha	14	1576.50	95.83	70.83	20.83	100.00
Adigudem	10	1205.15	91.66	75.00	16.67	100.00
Samre	6	1412.52	100.00	53.12	100.00	0
Hagereselam	3	1358.52	100.00	69.44	97.22	0

[a] Own survey results/calculation and Barnes et al. (2004) was used for conversion into KgOE.

[b] KgOE stands for kilogram of oil equivalent.

Table 5 Description of cooking appliances/ *injera* baking stoves used by sample households (n=350)

Stove type	Households involved	Percent
Open hearth (three-stone stove)	2	0.57
Tigrai-type (traditional clay enclosed)	324	92.57
Tehesh	4	1.14
Mirte	1	0.29
Electric *mitad*	71	20.29

Table 6 Probit model estimates (standard error in parenthesis) of electric *mitad* adoption[a]

Variable	Coefficient	Marginal effect
Price of wood	0.208	0.052
	(0.430)	(0.107)
Price of charcoal	-0.028	-0.007
	(0.399)	(0.010)
Price of kerosene	0.034	0.008
	(0.117)	(0.029)
Household income/expenditure (‘000 Birr)	0.061***	0.014***
	(0.019)	(0.00)
Family size	0.115**	0.028**
	(0.053)	(0.013)
Age of head	0.041***	0.010***
	(0.011)	(0.002)
Education of head	0.124**	0.031**
	(0.055)	(0.014)
Employment type/ occupation	0.043	0.011
	(0.051)	(0.013)
constant	-4.548***	
	(0.837)	
Pseudo-R^2	0.256	
LR $\chi^2(8)$	51.06	
Prob>χ^2	0.000	

[a] ***, and ** indicate statistically significant at 1%, and 5% level (or better), respectively.

Table 7 Probit results of household's fuel choice (dependent variable use of particular fuel)[a]

Regressor[b]	Traditional biofuels		Modern fuels	
	Wood	Charcoal	Kerosene	Electricity
Price of wood				0.719**
Price of charcoal	-0.421		1.563***	3.194***
Price of kerosene	0.134	0.551**		
Price of electricity		0.185	1.803	
Household income/expenditure ('000 Birr)	-0.014	0.122***	0.139***	0.020
Family size	-0.018	-0.137**	-0.045	0.028
Age of head	0.004	0.023**	-0.018**	0.023**
Education of head[c]	-0.165***	-0.024	-0.064	0.172**
Employment type/ occupation[d]	0.065	0.007	0.032	-0.084
Constant	1.816*	-1.343	-0.666	-2.626***

[a] This is a summary of individual probit regression by fuel good.

[b] ***, **, and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively.

[c] Education of head (highest grade completed) was captured on a 0, …, 11 scale; defined as 0=Illiterate, 1=Grade 1-3, . .. , and 11=Post graduate, respectively.

[d] Employment type/ occupation was captured as =1, if self employed; 0, otherwise.

Appendices

Table A.1 Final energy consumption of urban households in Ethiopia: Country overall and Tigrai

Fuel type	Country overall (1998/99)		Urban Tigrai (1995) Share (%)	Urban Tigrai (2003)[a]	
	Qty (in Tera Joules)	Share (%)		Qty (in Mega Joules)	Share (%)
Wood and tree residues	34,969.38	66.1	49.0	29,187.80	53.2
Crop residues	2,823.65	5.3	2.2	0.00	0.0
Dung	3,262.90	6.2	2.6	3,526.11	6.4
Briquette & biogas	0.00	0.0	0.0	0.00	0.0
Charcoal	5,855.81	11.1	40.9	15,666.16	28.5
Electricity	1,832.05	3.5	0.8	3,176.03	5.8
Petroleum fuels	4,161.24	7.8	4.4	3,325.77	6.1
Total	52,905.03	100.0	99.9	54,881.87	100.0

[a] Own survey results for representative household and RWEDP (1997) was used for conversion into energy units.

Source: ADC (2003) and EESRC (1995)

Table A.2 Energy/electricity production (country overall) by system/ source and year (in Giga Watt hour/GWh)

System/source	Year						
	99/2000	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06
ICS							
Hydro	1631.5	1774.3	1975.2	2007.1	2262.5	2521	2832
Diesel	4.0	2.1	0.1	21.1	16.1	18.4	12
Geothermal	20.0	5.1	1.0	0.0	0.0	0.0	0
Total	1655.5	1781.5	1976.3	2028.2	2278.6	2539.6	2844
SCS							
Hydro	14.3	15.5	16.6	16.5	16.5	17.9	19
Diesel	19.0	14.8	16.5	19.0	22.7	31.1	32
Total	33.3	30.3	33.1	35.5	39.2	49.0	51.0
ICS+SCS							
Hydro	1645.8	1789.8	1991.8	2023.6	2279.0	2539.1	2851.0
Diesel	23.0	16.9	16.6	40.1	38.8	49.5	44.0
Geothermal	20.0	5.1	1.0	0.0	0.0	0.0	0.0
Total	1688.8	1811.8	2009.4	2063.7	2317.8	2588.6	2895.0

Source: http://www.eepco.gov.et/ (Accessed 05 September 2008)