

Analysis of Household Cooking Fuel Choice in the Municipality of Andranonahoatra, Madagascar

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Abstract - Two rounds of surveys were carried out on a sample of households and all firewood and charcoal sellers inside the municipality. In reference to researches carried out in Madagascar and in other countries, this study verified that: – The vast majority of urban households use charcoal as their main cooking fuel – Many households also adopt one or two complementary fuels – The cleaner and more modern the complementary fuel, the higher the standard of living in the household – High standard of living is not the only one factor on which depends household cooking fuel choice. Choosing modern fuels did not replace traditional fuels – Several socio-economical and technical factors have negative or positive effects on cooking fuel choice. Indeed, the choice for a particular fuel is determined by several exogenous factors, among others, electricity bills, household size, the number of poultry cooking per month, the education level of family members. It is also identified the relationship between the consumption structure and the way charcoal is purchased, use of improved cookstove, and dwelling characteristics. Based on these findings, we try to model the fuel choice made by households in the municipality.

Keywords - Madagascar, Household Energy, Multinomial Logit, Marginal Effects.

I. INTRODUCTION

In Madagascar, a new energy policy based on renewable energy has been developed to mitigate the dual dependence of the energy supply, on the outside for petroleum products and on forest resources for household cooking fuels. Household sector is the most energy consumer in

Madagascar. It consumes about 90% of the country's total energy consumption of which origin are forest resources. Several studies have been conducted to provide solutions to this woodfuel problem, but most are still awaiting their achievements. This paper tries to help manage the resolution of the problem of this heavy dependence of households on

natural resources and consequently of the environmental degradation.

II. METHODOLOGY

The methodology developed for this study is based on the following considerations; on the one hand identifying factors influencing the cooking fuel choice; and on the other hand, modelling this choice to identify the class to which a household belongs. The aim is to be able to determine and predict energy behavior within each class of households.

Statistical analyses on the relationship between fuel choice, socio-economical characteristics, stove and cooking habits were carried out to identify and analyze explanatory factors and their effects on fuel choice, in order to categorize households.

To do this, we first conduct statistical study of quantitative and qualitative variables. Next, we adopt the multinomial logit model to determine the fuel choice made by households [1]. Thus, the factors on which household decision depend are the explanatory variables of the model.

2.1 The data

This study is based on the results of the work done by researchers [2], [3], [4], [5], [6], [7], [8] and above all on survey results carried out inside the municipality.

2.1.1 Study sites and sampling

The study was conducted in the seven fokontany which compose the commune. The sample size was determined using 97% confidence level, and level of precision 3%. Proportional sampling technique was employed to determine sample size in each fokontany [9]. Therefore:

$$n = \frac{N}{1 + N(e^2)}$$

N : Total of households,

n : household sample number,

e : level of precision.

From this formula, the survey was carried out with 1025 households in the municipality.

2.1.2 Consumption structure and fuel combinations

Our study shows that households in the commune depend almost entirely on solid fuels (98.4%) especially charcoal, for cooking. This is typical of urban households in developing countries [10]. In 2012, the percentage of households using solid fuels in the country was 96.9% [11]. This difference could be caused by the increase of the urban population number between the two years.

Table 1: Consumption structure

Fuel types	Household percentages	
	Primary fuel	Complementary fuel
Solid fuel (firewood, charcoal)	98,4	11,0
Non-solid fuel (gas, electricity)	1,6	22,1
Total	100,0	33,1

Source : Author (survey, 2018)

Table 1 shows that among the 98.4% households using solid fuels as their primary fuel, 11% have a complementary fuel. A total of 33.1% of households use at least one adding fuel for cooking. In 2012 it was 6.9% in country level [11]. From this global view, households can still be divided into several classes according to the details of the fuels used within each class, as the following figure shows.

This figure shows that about 66% of households use charcoal-alone in the kitchen. It can be caused by affordability and household's easy accessibility to charcoal and availability from local markets. Furthermore, a complete dependence on a single fuel may make households vulnerable to price variation and unreliable service/supply

[1]. Firewood-only, gas-only or electricity-only are used by about 1%. The remaining 33% are combinations of charcoal, firewood, gas and electricity. It should be noted that in all these combinations, about 32% of households use charcoal as their primary fuel. Non-solid fuels (also known as modern fuels) are used by only 0.9% and 0.7% respectively as primary fuels. In addition, 4% and 20% of households use respectively gas and electricity as secondary or tertiary fuels. These percentages show that households in the commune rely heavily on forest resources for cooking meals.

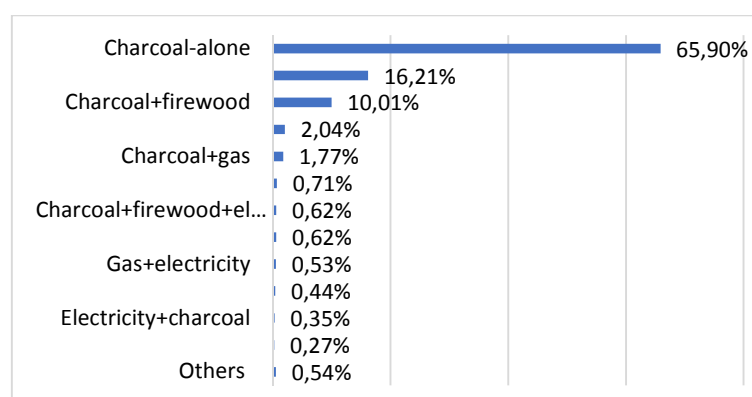


Figure 1: Household classification by fuel combinations

2.1.3 Household size

Based on Table 1, the results of descriptive statistics allow to divide households into five distinct and homogeneous classes [12], [13], [14] : charcoal-alone (C), charcoal and firewood (CF), charcoal and gas (CG), charcoal and electricity (CE), gas or electricity and other fuels (GE+). For the first four classes, charcoal is the primary fuel supported by firewood, gas or electricity for cooking. While for the fifth class (GE+), it includes all households whose primary fuel is either gas or electricity, followed by other fuels. Table 2 summarizes this household classification using household mean size of each class.

Table 2: Household Size by class

Class	Percentage	Mean size	Std deviation
Charcoal-alone (C)	73.7%	4.5	1.769
Charcoal+Firewood (CF)	6.8%	4.9	1.792
Charcoal+Gas (CG)	3.7%	5.3	1.938
Charcoal+Electricity (CE)	14.2%	4.9	1.726
Gas-Electricity+others (GE+)	1.6%	4.5	2.493
Total or Mean	100%	4.8	

Source : Author (survey, 2018)

In Table 2, the following facts should be noted:

- Among the classes that have complementary fuels, the CF class that adds firewood to charcoal is fewer than that adding electricity to charcoal (CE class, 14.2%). This confirms the results of several researchers attributing firewood as the first fuel of rural households, especially the poor [13], and

charcoal plus or not gas or electricity for city dwellers. The commune is therefore in an urban setting. By using firewood in the kitchen, CF class households therefore behave like rural households in the cooking mode and may also be in the cooking habit.

- Households of CG and CE classes are in a kind of intermediate or transition class between those who use charcoal as primary fuel and those primarily dependent on gas or electricity (GE class) [15], [16], [17].
- Even in very small percentages (1.6%), the GE+ class proves that some households in the municipality have already partially or completely replaced solid fuels (wood and charcoal) with modern fuels (gas and electricity). In other words, these households have already made significant progress in energy transition. We will discuss these facts in more detail in other study related to energy transition.

Still in Table 2, we note that the average household size of the commune (4.8) is higher than the national average (4.0) in urban areas. It is a densely populated commune like several other urban municipalities around the capital. This classifies the commune between the poor and the middle level in terms of consumption quintile [11].

It is also shown that, generally, households using solid fuels, i.e. classes C, CF, CG and CE, have higher average sizes than the class using gas or electricity as primary fuel, GE+ [14]. In other words, as long as a household uses charcoal as its primary cooking fuel, its size is larger than that with gas or electricity. Theoretically, the size of the GE+ class reflects a higher standard of living through

certain criterias, including electricity bills, dwelling type, level of education of the household's head and of family members [19], and the frequency of poultry cooking.

2 - 2 Fuel choice modelling

For the choice modelling, due to the specificity of the GE+ class, we limit our study to the four classes (C, CF, CG and CE classes) that share charcoal as their primary fuel. The process is therefore to model the decision of a household to choose one among the four classes mentioned above based on relevant variables.

Suppose a household has to make a rational choice between four modalities (charcoal plus one secondary fuel combinations) giving different levels of satisfaction. It is possible that this choice may have a misperception of the quality of the different modalities, or there is a difficulty for households to accurately assess utility levels [20]. It is also assumed that satisfactions resulting from rational choices may correspond to a utility function that characterizes a certain level of well-being. Consider the case where the utility level is described by a U_{ij} function. So, a household i has to make a choice j among m modalities. In our context, j represents the four classes of households and varies from 1 to 4. We have:

$j=1$ for class C; $j=2$ for class CF; $j=3$ for CG and $j=4$ for class CE.

The result of the model depends on the vector of socio-economic and demographic variables X_i of the household i . As these characteristics differ from household to household, the decision that comes out of them may also be different. By applying a classical micro-economy approach, household i tries to maximize its utility U_{ij} by choosing one among the m fuel classes. We've got:

$$U_{ij} = \beta_j X_i + \varepsilon_{ij} \quad j = 1, \dots, m \quad (a)$$

β_j represents the vector of the coefficients of the model corresponding to fuel j .

ε_{ij} is a non-observable term.

X_i represents the vector of the socio-economic and demographic variables of the household i .

It is assumed that the β_j differ according to the modalities and for which the explanatory variables vary only according to the households.

One defines $\Pr(y = j)$ as the probability for a household to choose the modality j , $o \ j = 1, \dots, m$.

$$\Pr(y=j|x_i) = \Pr(y_i=j) = \Pr(U_{ik} > U_{ij}, o \ k \neq j) \quad (b)$$

$$\Pr(y_i=j) = \Pr(\beta_k X_i + \varepsilon_{ik} > \beta_j X_i + \varepsilon_{ij}, o \ k \neq j)$$

$\Pr(y_i = j)$ is equal to 1 if class j is chosen by household i , and 0 for all other choices.

Therefore, by adopting a multinomial logit model [21] :

$$\Pr(y_i=j) = P_{ij} = \frac{e^{(\beta_j X_i)}}{\sum_{k=1}^m e^{(\beta_k X_i)}} \quad k = 1, \dots, m \quad (c)$$

From equation (c), using modality 1 (class C, charcoal-alone) as the reference modality, and under the normalization hypothesis $\beta_1 = 0$, we have:

$$\Pr(y_i=1) = P_1 = \frac{1}{1 + \sum_{k=2}^m e^{(\beta_k X_i)}} \quad k = 2, \dots, m \quad (d)$$

The log-likelihood is written:

$$L = \sum_{i=1}^n \sum_{j=1}^m P_{ij} \log(\Pr(y_i = j|x_i))$$

To estimate the parameters β_j of the model, it is sought to maximize the L function. The maximum likelihood method is therefore used to estimate the multinomial logit model.

In our context, since the modality 1 constitutes the reference, the charcoal will be eliminated from the choice, since all the classes use it as primary fuel. This means to modeling the choice of a secondary fuel for a household i , that is to say the choice between firewood, gas and electricity.

It remains to estimate the β_2 , β_3 and β_4 coefficients relating to modalities 2, 3 and 4.

III. RESULTS AND DISCUSSIONS

After Correspondence Factor Analysis, Multiple Correspondence Analysis and Principal Component Analysis between modalities and explanatory variables, we identify, among many others, ten main variables that have effects on household cooking fuel choice. Trying to consider all the characteristics which can influence the household choice, we classify these variables into three types: *Socio-demographic* variables - *Economic and financial* variables (called also *standing* variables) - *Equipment* variables. Four of them are quantitative, six qualitative. One may ask why income is not included in the list of our independent variables. Chosen variables depend on the answer of the responder. We have found during the survey that almost all responders did not give reliable answers about income. But, knowing that income is an important variable for fuel choice, according to many researchers, we believe it is

represented by the standing variables taken in this study. Variables are defined in the following table.

Table 3: Variable definitions and descriptive statistics

Variable x_i	Definition	Min.	Max.	Mean	Std deviation
Electricity	Natural logarithm of monthly electricity bill (Ar. per capita)	0,000	11,003	8,235	1,966
Size	Family size	1,000	10,000	4,540	1,652
Poultry	Frequency of poultry cooking per month	0,000	30,000	1,529	3,437
Baccalaureate	Number of people in the family with a baccalaureat's degree	0,000	7,000	0,618	1,098
ICS	Use of Improve CookStove : yes = 1; 0 otherwise	0	1	0,793	0,405
High	Household's head has a high school degree : yes = 1; 0 otherwise	0	1	0,428	0,495
University	Household's head has a university degree : yes = 1; 0 otherwise	0	1	0,204	0,403
FRG	Use of a fridge : yes = 1; 0 otherwise	0	1	0,165	0,371
Sack	Sacked charcoal purchase : yes = 1; 0 otherwise	0	1	0,552	0,497
Owner	Dwelling ownership : yes = 1; 0 otherwise	0	1	0,753	0,431

The results of the estimate model, for both quantitative and qualitative variables, are presented in Table 4 which makes it possible to determine the impact of each exogen

variable on the probability of belonging to such or such class.

Table 4: Multinomial logit estimates

Exogen variables	Firewood	Gas	Electricity
Intercept	0,53404 (0,6011)	-14,70104 (3,3607)***	-7,88433 (1,6216)***
Log of electricity bill	-0,42208 (0,0485)**	0,85277 (0,3232)***	0,46448 (0,1654)***
Household size	0,24537 (0,0959)**	0,15242 (0,1348)	0,12908 (0,0754)*
Frequency of poultry cooking	-0,02549 (0,0888)	0,09617 (0,0316)***	0,04746 (0,0271)*
Number of baccalaureate degree	-0,60216 (0,3799)	0,46837 (0,1434)***	0,22877 (0,1048)**
ICS (yes)	-0,94060 (0,3361)***	0,41650 (0,6763)	-0,80969 (0,2864)***
High school degree (yes)	-1,09976 (0,3528)***	0,47883 (0,6868)	-0,19100 (0,3046)
University degree (yes)	-2,27249 (1,1459)**	1,06691 (0,7074)	1,12221 (0,3200)***
FRG (yes)	-1,55919 (1,2719)	1,78889 (0,4442)***	1,62525 (0,2629)***
Charcoal in sack (yes)	0,43478 (0,3356)	1,08791 (0,5976)**	0,97484 (0,2816)***
House ownership (yes)	0,15919	0,34234	0,64788

	(0,3620)	(0,4908)	(0,2967)**
Observation numbers	939		
Log likelihood	-509,996		
LR Khi-2(33)	465,83***		
Pseudo-R ²	0,3135		
Standard errors in parentheses. Significant level : *** <1% ; ** <5% ; * <10%			

Source : Results of multinomial logit regression

The $\beta_j(s)$ estimated by the model relate the statistical significant of the variables. They make it possible to evaluate the degree of certainty with which a variable influences the choice to belonging to one of the three classes [22] by looking at the thresholds of significant of each parameter.

For significant parameters at the 1% level, it is safe to say that the corresponding variables influence the orientation of fuel choice. The effect is real and does not depend on the hazard of the sample [23].

From Table 4, therefore, having an ICS and a high school diploma have a very significant influence ($p < 1\%$) on belonging to the class of households choosing firewood as a secondary fuel. Same thing for the variables cooking frequency of poultry, number of bacculaureate in the family and the possession of a fridge for belonging to households adopting gas. Likewise, having an ICS and a fridge is significant at 1% level to belong to the electricity class. At the same time, owning the house has a significant influence on the choice of firewood and gas, just like having done a secondary study for the choice of gas and electricity.

In our study, 20 out of 33 estimated coefficients (60%) are significant at less or equal to 10% level, of which 14 to 1% (42%). LR-Khi2 is 465 and is significant at 1% level. We think that with these numbers, we can exploit the model.

Speaking about parameters, it is the marginal effects (dy/dx) that make it possible to evaluate the impact of the explanatory variables on the fuel choice. According to References [7], [21], [24], the $\beta_j(s)$ of the model are difficult to interpret. The marginal effects estimated by the model are more significant and easier to explain. Deriving the previous equation (d), the marginal effects of household characteristics on the choice probability are defined as follows [7], [21], [24] :

$$\delta_j = \frac{\partial P_j}{\partial x_i} = P_j [\beta_j - \sum_{k=1}^m P_k \beta_k] = P_j [\beta_j - \bar{\beta}] \quad (e)$$

From equation (e), the marginal effects measure the change obtained by a unit of variation of an explanatory variable x_i on the probability P_j of choosing each of the four types of fuel. In our context, remember, the combinations are: charcoal-alone, charcoal-firewood, charcoal-gas and charcoal-electricity. Note that δ_j is not necessarily the same sign as the corresponding β_j [7], [21]. The marginal effects are presented in the following table.

Tableau 5. Marginal effects of multinomial logit estimates

Explanatory variable	Without	Firewood	Gas	Electricity
log of electricity bill	-0,02304 (0,0121)*	0,03518 (0,0060)***	-0,08377 (0,0245)***	-0,08544 (0,0263)***
Household size	-0,02001 (0,0068)***	-0,0341 (0,0121)***	-0,02172 (0,0110)**	-0,02555 (0,0122)**
Frequency of poultry cooking	-0,00317 (0,0041)	0,00142 (0,0108)	-0,00901 (0,0037)**	-0,00924 (0,0043)**
Number of bacculaureate degree	0,00397 (0,0175)	0,06520 (0,0468)	-0,04120 (0,0138)***	-0,03870 (0,0172)**
ICS (yes)	0,08480 (0,0261)***	0,13772 (0,0428)***	0,0778 (0,0470)**	0,10833 (0,0480)**
High school degree (yes)	0,05082 (0,0269)*	0,13836 (0,0443)***	0,00747 (0,0465)	0,02423 (0,0495)

Explanatory variable	Without	Firewood	Gas	Electricity
University degree (yes)	0,00686 (0,0535)	0,24016 (0,1403) *	-0,15590 (0,0502) ***	-0,15857 (0,0538) ***
FRG (yes)	-0,06287 (0,0558)	0,13630 (0,1562)	-0,24447 (0,0322) ***	-0,25924 (0,0390) ***
Charcoal in sack (yes)	-0,09315 (0,0246) ***	-0,08508 (0,0419) **	-0,15424 (0,0445) ***	-0,17314 (0,0457) ***
Dweller ownership (yes)	-0,05208 (0,0261) **	-0,03973 (0,0449)	-0,08647 (0,0414) **	-0,10112 (0,0470) **

Source : Multinomial logit model output. Significant level : *** p<1%, ** p<5%, * p<10%

We give below the practical meanings of the marginal effects estimated by the model by grouping them according to three groups of variables.

Effects of socio-demographic variables

Among the eleven explanatory variables, household size has a significantly negative effect for all choices. In fact, for every one person increase in the family member, the probability of choosing charcoal-alone, gas and electricity decrease by 2% to 2.5% ; 3.4% decrease in the probability of using firewood. To some extent, this is contradictory to what some researchers found, saying that larger households are more likely to consume multiple fuels, both biomass and non-biomass [10]. The facts are real especially for charcoal-alone and firewood choices (p<1%). While for the probabilities of choosing gas and electricity, the significants are 10% and 5% respectively. The choices for charcoal-alone and for firewood are therefore more sensitive to changes in household size than for gas and electricity. This could be because households using solid fuels are generally poorer than those adopting non-solid fuels.

The number of baccalaureate graduates is significant at 1% and 5% levels respectively for gas and electricity choices. Contrary to expectations, increase of the number of high school graduates in the household decreases the probability of choosing gas and electricity by about 4%. The fact that the household's head has reached the level of secondary education increases the probability of choosing charcoal-alone by 5.1% and 13.8% for firewood. This variable is significant at 10% and 1% levels respectively for these two fuels. The majority of the household heads are in this level of study. Some urban households are behaving like rural household by using firewood [25].

Whereas for a household's head with a university study, contrary to the results of some researchers [14], [15], the probability of choosing gas decreases by 14.8%; 15.8% for electricity (p<1%). This confirms in part the effect of the

variable number of baccalaureate graduates cited above. Against all odds, this university study variable increases the probability of choosing firewood by 23.7% (p<10%).

Effects of standing variables

Electricity bill are one of the variables that are significant for all choices. Indeed, for this variable, the facts are real for the choice of firewood, gas and electricity, with a significant level of 1%. An increase of one unit in electricity bill increases the probability of choosing firewood by 3.5%, while decreasing the probability of choosing gas and electricity by more than 8%. For charcoal-alone, the decrease in probability is 2.25% with a significant of 10%. Note that most households using gas and electricity already have a much higher electricity bill than those burning only charcoal and firewood. To counterbalance this already high expenditure, a 1% increase in this expense incites households to turn to cheaper fuel than gas and electricity.

The frequency of poultry cooking is significant only for the choice of gas and electricity (p<5%). An increase of one unit in the number of poultry cooking per month reduces the probability of choosing these two fuels by about 0.9%. This is because eating poultry relates a high standard of living, so for households cooking with gas and electricity. However, this decrease of the probability reflects the idea of some households to limit their energy bill by cooking poultry with firewood or charcoal.

Like the electricity bill, purchasing charcoal sack is significant for all choices (p<1%) except for firewood (p<10%). In addition, it decreases all probabilities of choosing secondary fuels. The decrease is 8% to 9% for solid fuels and 15.9% to 17.6% for non-solids. This reflects the high price of the charcoal, especially during the rainy season, causing some households to switch to other fuels.

Dwelling ownership decreases the probabilities of choosing all the secondary fuels except firewood. These decreases confirm the results obtained from households in Ouagadougou [7].

Effects of equipment variables

The model shows that using an ICS increases the probability of using all fuels. The level of significant is very high for solid fuels ($p < 1\%$) and 10% for non-solids. This proves the practical use of ICS in developing countries where many families stay in mixenergy even after adopting modern fuels [1], [25].

Possessing fridge is a typical variable of standard of living, so as for rich household. The use of a refrigerator decreases the probability of using gas by 23.9% and electricity by 25.8%. It seems contradictory, but using fridge allows to keep an already prepared meals, thus decreasing the number of cooking [26] which is a good advantage for wealthy family. The variable is significant at 1% level for gas and electricity choices. Using ICS is also one of the variables that affects all choices. The level of significant is very high for solid fuels ($p < 1\%$), and 10% for non-solids.

IV. CONCLUSION AND RECOMMENDATIONS

The municipality of Andranonahoatra can be used as a model for municipalities of its rank to study the energy sector, especially household cooking fuels. We, therefore have found that the cooking fuel choice is a complex system involving many factors. In this study, the survey results showed that households use charcoal as their primary source of cooking energy. It has been shown through a multinomial logit model that socio-economic, demographic and technical characteristics have an effect on the choice of households to choose particular secondary fuel. Thirty out of forty of the marginal effects values calculated by the model are significant at a level of 10%, which is reasonable for the field studied and compared to the results of the research already carried out. Therefore, the model used showed that among the ten variables studied, four have a significant marginal effect on the probabilities of choosing all fuels. These are the amount of the electricity bill, the size of households, the use of improved cookstove and the way of purchasing charcoal.

The model results also show that household size, sacked charcoal purchase, and dweller ownership have negative marginal effects on the probabilities of choosing all fuels. While possessing improved cookstove has a positive marginal effect for all choices. The list of variables considered in this study is not exhaustive, but it would be

desirable for policymakers to take into account the effects of these variables when developing energy policy aimed to supply household energy at lower cost, and also protect the environment.

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