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HOUSEHOLDS ENERGY CONSUMPTION AND TRANSITION TOWARDS CLEARNER ENERGY SOURCES

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The paper investigates the factors influencing households' energy choices, and the drivers of switching toward cleaner energy. We first present a theoretical framework to determine the factors that explain households' energy consumption and highlight the motivations underlying their transition towards less polluting sources, including their environmental preference. Using French household data from ADEME, we provide an econometric test of qualitative variables following studies by Dubin and McFadden (1984). Our results show that income and prices are the main determinants of household energy consumption. Environmental considerations seem to influence the choice of energy sources more than consumption. We also find evidence that income and relative capital costs are the most important variables for household energy switching.

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1 Introduction

This article focuses on the factors that determine the households' energy consumption and, the drivers of switching toward cleaner energy. The reasons for interest in this analysis are manifold. Indeed the most recent report of the Intergovernmental Panel on Climate Change (IPCC) shows that the increase in global temperatures could be as high as 4.8 degrees C by 2100 (GEIEC, 2014)[19]. In response to this report, an agreement was signed (COP21) to keep global warming below 2 degrees C. To a large extent, the increase in temperature is due to the steady increase in greenhouse gas (GHG) emissions from the energy sector (IEA, 2015)[29]. Thus the 2 degrees C objective cannot be achieved without a real energy transition, involving renewable energy production development and changes in consumption habits. Effective action in the energy sector is therefore essential for fighting climate change (IEA, 2015)[29]. In this respect, certain countries, such as France and Germany, have implemented policies and strategies to encourage cleaner energy consumption and greater energy efficiency. In France, the energy transition law for green growth (LTECV) enacted in 2015 moves in this direction. In Germany, the renewable energies act (EEG) was adopted in 2000 and reviewed in 2016. These various actions aim to reduce greenhouse gas emissions by 40% by 2030 for France and by 2020 for Germany compared to 1990. In addition, France is also planning to increase the share of renewables from 14.9% today to 32% and to reduce its final energy consumption, estimated at 162 Mtoe, by 20% by 2030.

The building sector generally accounts for a high proportion of energy consumption. In France, for instance, it is the largest energy consumer with 44%, of which two-thirds is attributed to the residential sector. This figure represents more than 20% of national CO_2 emissions (ADEME, 2014) [2]. Fossil fuels still account for 48% of the primary energy package. Overall, the residential sector has great potential for GHG emissions reduction, that public policies are aiming to exploit. To make the most of these efforts, it is crucial to determine the variables explaining household energy consumption and the factors underlying their transition to cleaner sources. Several studies have focused on household energy consumption. However, most of them assume that the discrete choices made by households are linked to continuous choices. For example, a household's decision to choose an energy source i (discrete) will also depend on the energy quantity qi to be consumed. Dubin and McFadden (1984)[16], studying American households' electricity consumption and residential appliance holding, propose for the first time a discrete/continuous choice model to capture this interdependence. Following them, other authors have applied this type of model. Bernard et al (1996) [9] analyze household electricity demand in Quebec. Vaage (2000) [48] estimates Norwegian household energy demand, highlighting the existence of a significant impact of income on the choice probability and a negligible effect on demand. Price elasticities are found to be significant and negative. Nesbakken (2001) [43] considers that discrete and continuous choice does not occur during the same period. Indeed, his idea is that many households do not explicitly choose the heating system, because this choice is made at the time of house building, whereas the energy quantity choice is made in the current period, after households take up residence. In his specification, this author jointly takes into account the choice of space heating system at one point in time and the intensity of use at a later point in time. Similarly, Liao and Chang (2002) [32] analyze heating energy demand by the elderly in the United States. They show a positive effect of age on space heating and a negative effect on hot water requirements. Couture et al. (2011) [14]focus on French households' fuel wood consumption, considering the type of wood use as the main or a secondary energy source. These authors variously consider individuals who don't use wood (non-users), wood users for the main energy source, and those who use it for back-up heating. Using the Dubin and McFadden (1984) [16] model, Bourguignon and al. (2007) [11] show that, first, the choice of wood as the main source of heating energy is negatively linked to income, and second, the price of wood doesn't seem to affect wood choice probability for any use. However, based on the fact that the price of other energies is rising faster than that of wood, they argue that a substitution effect would arise between wood and other energy sources (gas, oil and electricity).

However, household fuel wood demand may also be affected by location[4](Aguilar et al ., 2012) [5]. These authors argue that the differences in levels of wood energy consumption may be due to differences in the availability and price of wood, as well as the household's intrinsic preferences.

From another angle, Michelsen and Madelener (2016)[36] investigate drivers and barriers behind decisions of homeowners in Germany to switch from a fossil fuel to a renewable heating system. They use data from surveys of homeowners who changed their oil or gas heating systems for a new oil or gas boiler with solar thermal support, a heat pump or a wood pellet boiler between January 2009 and August 2010. Their empirical approach involves a two-step method to obtain a differentiated understanding of the determinants of both the positive and negative adoption decision. The first step is based on a binary logit model, so as to understand the factors that determine the adoption of a renewable energy heating system, and the second step uses a multinomial logit model to understand the factors that explain the choice of gas or oil boiler, heat pump or wood pellet boiler [5]. They show that environmental protection, low dependence to fossil fuels and knowledge about heating systems are the main determinants of switching from fossil fuels to renewable energy sources. They also draw attention to various obstacles to the energy transition, such as the difficulty of getting used to the system and failure to understand its functioning for the heat pump. In the case of wood pellet boilers, non-adoption is mainly due to functional barriers related to use and risk. Indeed, maintenance costs (for example sweeping and cleaning), and heating system maintenance and repair limit wood pellet boiler adoption. Uncertainty related to wood price fluctuations is also an obstacle.

Overall, the energy consumption literature has mainly focused on socio-economic factors, demographic characteristics, housing types, etc. To our knowledge, household environmental preferences haven't yet been taken into account in energy choice and

[4]For example, in the United States, households in different areas (urban / rural areas) consume wood energy at different levels.

[5]This step concerns individuals who have initially a choice between a gas or oil-fired boiler with a solar thermal, heat pump or a wood pellet boiler and finally chose a gas or oil-fired boiler with a solar thermal

consumption. Nevertheless, opinions on the negative effects of energy consumption require the incorporation of environmental sensitivity into the analysis of individual behaviors in terms of energy consumption. The contribution of this paper is twofold. First, it makes a link between the literature explaining households' energy consumption choices and the literature investigating the drivers of transition towards less polluting sources. Second, it takes into account the households' environmental preference in their energy choice and consumption. In other words, what are the determinants of household energy consumption? What are the drivers behind the transition to cleaner energy sources? To address these questions, we use an original database, constructed on the basis of national surveys of energy use in France and the characteristics of households and dwellings, carried out by ADEME. This micro-economic database was partially used on investment decisions for household retrofits in a study by Nauleau (2012) [42]. This database (38557 observations) is higher than the data used in previous studies, such as Couture et al., (2012) [14] from the household wood energy consumption survey, carried out in 2006 by the BVA survey institute and covering only the Midi-Pyrénées region, or Hache et al. (2016) [21], who use a larger database from the INSEE housing survey (2006). The variables used in these studies are often economic (income, prices, energy expenditure, consumption) and household characteristics. Our data, like that used by Hache et al. (2016) [21], concern the whole of France and have the advantage of taking into account the household's environmental sensitivity (objective[6] and subjective[7] sensitivity, capital costs and the household's switching decision.

Our empirical approach is based on a two-step method: a discrete/continuous choice model is used in the first step to analyze household energy consumption for all uses. First, we estimate the discrete model (multinomial logit model) by the maximum likelihood method, and the selection of bias correctors associated with the chosen alternative is then made. Second, the conditional demand for the chosen alternative is estimated by adding the bias correctors. We then use a binary logit model to

[6]The household takes into account the environment when choosing its energy source.

[7]The household considers that environmental issue are more important or that the government priority should be to promote renewable energies and fight against global warming.

analyze the switching probability for heating.

Our results show that environmental preferences (objective and subjective variables) influence the household's energy choice. The results suggest that when a household explicitly takes into account the environment when choosing its energy source, the probability of choosing wood increases by 0.33 percentage points and of choosing electricity by 6.74 percentage points. However, when the household considers that environmental issues are more important or that the government priority should be to promote renewable energies and fight against global warming, these marginal effects are estimated to rise to 3.36 and 26.64 percentage points for wood and electricity respectively. However, environmental variables have no effect on households' energy consumption. Indeed, environmental considerations have more effect on the energy choice than on consumption.

In addition, the income effect is significant on energy choice. Indeed, lower-income households are more likely to choose wood as their main energy source, while a higher income leads to the choice of electricity and gas. However, its impact on energy demand vary from one source to another. Income has no effect on wood demand but positively and significantly influences electricity and gas demand. Price elasticities associated with the different sources are all negative and significantly different from zero. Prices seem to explain well fluctuations in energy demand, but its variation impacts more on wood demand.

Regarding the households' energy switching, it is largely influenced by income and the relative capital cost. Higher-income households are in general more likely to switch than lower-income households, while the influence of relative capital cost on the probability of switching is significantly negative.

The rest of the paper is organized as follows. Section 2 presents the theoretical model of energy consumption and household switching decision. The econometric specification and empirical strategy are discussed in section 3, while section 4 describes the methodology and data used. The results from the econometric analysis are reported and discussed in section 5. Section 6 presents the conclusion and discussion.

2 Theoretical Framework

2.1 Households energy consumption

We consider a representative household choosing its energy consumption, maximizing utility subject to a budget constraint. The household first chooses the type of energy source it will use $i = 1, ..., I$, and then the quantity of energy q_i it will consume. Choosing a source of energy implies to invest in a durable good of initial value K_i. The durable good lasts for $\overline{T}$ periods. To keep simple, we assume that the household pays each period a share $s/\overline{T}$ of the initial value. Thus, the durable good is entirely paid when its residual value goes to 0, after $\overline{T}$ periods. We assume that there is no second market, so that a durable abandoned before its lifetime expires does not bring any additional revenue. The model is solved backward.

2.1.1 Optimal energy consumption

Utility is increasing in energy consumption q_i and consumption of a composite good x, used as a numeraire. It is also decreasing in CO2 emissions, $E_i(q_i) = e_i q_i$, involved by the energy source i. e_i represents the emission factor of energy source i. We assume standard properties of the utility function: $U(q_i, x, E_i)$ is increasing and concave in q_i and x; and is decreasing and convex in $E_i(q_i)$: $U_{q_i} > 0$, $U_{q_i q_i} < 0$, $U_x > 0$, $U_{xx} < 0$, $U_{E_i} < 0$, $U_{E_i E_i} < 0$.

The household optimization problem is thus, at each period, to maximize utility:

$$\begin{aligned} \max_{q_i, x} \quad & U(q_i, x, E_i(q_i)) \\ s.t \quad & Y \geq p_i q_i + x + \frac{sK_i}{\overline{T}} \\ & E_i(q_i) = e_i . q_i \end{aligned} \tag{1}$$

with Y the household's income and p_i the price of energy i.

First-order conditions implicitly give the optimal consumption of energy and of the composite good. $q_i^*(p_i, Y, K_i, s, e_i, \overline{T})$ and $x^*(p_i, Y, K_i, s, e_i, \overline{T})$ are implicitly given by:

$$\begin{aligned} \frac{U_{q_i} + e_i U_{E_i}}{U_x} &= p_i \\ p_i q_i^* + x^* + \frac{sK_i}{\overline{T}} &= Y \end{aligned} \tag{2}$$

Standard results arise from this first step: consumption of energy i is decreasing in its price, in the cost of the durable good and, increasing in income.

Result 1: *consumption of a given energy source is decreasing in the household's environmental preferences (desutility from CO2 emissions). Similarly, for two different energy sources of same price, the household would tend to consume a larger amount of the cleaner energy source.*

2.1.2 The choice of energy source

In the first stage, the household chooses its energy source, considering its optimal consumption of the second stage, given energy prices, income and the cost of the durable good. Moreover, at every period, they consider whether it is profitable to them to switch their source of energy.

The household can decide to switch from its initial energy source j to energy source i either at the end of the durable lifetime or before the end of the durable lifetime.

2.1.2.a Switch at the end of the durable lifetime

When the durable good is entirely paid, and has no residual value, it is necessary to invest in a new durable. Households can switch their source of energy at no additional cost. Households choose energy source i over any other source of energy if it maximizes its expected discounted utility:

$$\begin{aligned} \int_0^{\overline{T}} \delta^t U(q_i^*, x^*, E_i(q_i^*))dt > \int_0^{\overline{T}} \delta^t U(q_j^*, x^*, E_j(q_j^*))dt \ , \forall j \neq i \\ q_i^* = q_i^*(p_i, Y, K_i, s, e_i, \overline{T}) \ , \ \forall i = 1, ..., I \\ x^* = x^*(p_i, Y, K_i, s, e_i, \overline{T}) \ , \ \forall i = 1, ..., I \end{aligned} \tag{3}$$

with δ the discounting factor. p_i is the long-term expected price of energy i. We assume that all variables $(Y, K_i, s, \overline{T})$ are stable in time.

Equation (3) implies a relative price threshold under which switching technology from energy source i to energy source j is optimal.

$$\frac{P_i}{P_j} \leq \overline{p}(Y, K_i, K_j, s, e_i, e_j, \overline{T}), \ \ , \forall j \neq i \tag{4}$$

Result 2: *The household chooses energy source i at the end of the previous durable lifetime if the price ratio of this source to any other source is below a certain ratio. This ratio is decreasing in its durable cost, increasing in the cost of the other sources durables, increasing in the emission factor of source i and decreasing in the emission factors of the other sources:* $\frac{\partial \overline{p}}{\partial K_i} < 0$, $\frac{\partial \overline{p}}{\partial K_j} > 0$, $\frac{\partial \overline{p}}{\partial e_i} > 0$, $\frac{\partial \overline{p}}{\partial e_j} < 0$.

Note that the effect of income, cost of capital and durable lifetime are not determined.

2.1.2.b Switch before the end of the durable lifetime

Moreover, households can decide to switch their source of energy before the durable good is completely depreciated (or paid). Each period, the household decides to switch or not from its initial energy source $\tilde{i}$ to a new source i. If the choice of switching is made, households have to pay for both durable goods for some periods (a remaining fraction $\alpha < 1$ of $\overline{T}$), and the new budget constraint is then: $Y = p_i q_i + x + \frac{sK_i}{\overline{T}} + \frac{sK_{\tilde{i}}}{\overline{T}}$. Thus the optimal levels of consumption for those periods are: $q_i^{**}(p_i, Y, K_i, K_{\tilde{i}}, s, e_i, \overline{T}) < q_i^*$; $x^{**}(p_i, Y, K_i, K_{\tilde{i}}, s, e_i, \overline{T}) < x^*$.

Two conditions are necessary to switch in this case. First, energy source i must be the one providing the highest level of discounted utility- hence equation (4) must hold. Second, switching immediately to energy source i provides more discounted utility than waiting for the end of the durable lifetime to switch.

The condition for switching before the end of the durable lifetime is thus:

$$\int_0^{\alpha\overline{T}} \delta^t U(q_i^{**}, x^{**}, E_i(q_i^{**}))dt \geq \int_0^{\alpha\overline{T}} \delta^t U(q_{\tilde{i}}^{*}, x^{*}, E_i(q_{\tilde{i}}^{*}))dt \tag{5}$$

The threshold for such a choice to hold is thus:

$$\frac{P_i}{P_{\tilde{i}}} \leq \overline{\overline{p}}(Y, K_i, K_{\tilde{i}}, s, e_i, e_{\tilde{i}}, \overline{T}, \alpha) \tag{6}$$

Result 3: *The household chooses energy source i before the end of the previous durable lifetime if the price ratio of this source to previous source $\tilde{i}$ is below a certain ratio. This ratio is decreasing in its durable cost, decreasing in the cost of durable of source $\tilde{i}$, increasing in the emission factor of source i, decreasing in the emission factors of source $\tilde{i}$, and decreasing in the remaining fraction of the previous durable lifetime:* $\frac{\partial\overline{\overline{p}}}{\partial K_i} < 0$, $\frac{\partial\overline{\overline{p}}}{\partial K_{\tilde{i}}} < 0$, $\frac{\partial\overline{\overline{p}}}{\partial e_i} > 0$, $\frac{\partial\overline{\overline{p}}}{\partial e_{\tilde{i}}} < 0$, $\frac{\partial\overline{\overline{p}}}{\partial \alpha} < 0$.

3 Econometric specification

3.1 Energy consumption

Since the MC Fadden studies (1973, 1974)[34] [35], the multinomial logit model has emerged as a statistical tool to model the discrete choice between several alternatives. It is frequently used because of its simplicity for analyzing discrete choices (Bourguignon et al.,2007) [11].

These models, which have been used in several applications in many fields (social sciences, medicine, etc.), will be used here to analyze household energy consumption. Consider U_i, the random utility level associated with choice i:

$$U_i = V(X_i, \beta) + \epsilon_i \tag{7}$$

With $V(X_i)$ is the deterministic term which depends on a set of explanatory variables X_i, β the vector of unknown parameters and ϵ_i the random term of the model that can be define as the difference between the unobserved utility and the part of utility that we try to capture in $V(X_i)$. For example the utility of a consumer who chooses wood U_{wood} is unobserved. We simply observe some individuals and alternatives attributes (income, prices, environmental variables, etc.) and from this we specify a function that links these observed factors to the individual decision[8].

The demand functions developed in Section II can be written as follow:

$$q_i = \delta_i Z_i + \mu_i \tag{8}$$

With q_i, the quantity of energy consumed by the household in the energy source i, Z_i is the vector of the explanatory variables, δ_i the parameters to be estimate and μ_i the error term.

The household can choose among four energy source (wood, electricity, gas and fuel oil) and we suppose that the alternatives are exhaustive and mutually exclusive[9]. For example, a household who chooses wood can not in any case choose another type of energy source.

The choice decision for a given energy source derives from the utility function. Indeed, the decision maker will choose the source i if it gives him the most utility, compared to the other sources. In other words, if $\forall\ k \mp i$, $U_i > U_k$, the category i will be prefered to k.

Formally, we have:

$R_h = i$ with R_h is an observed variable that indicate the household choice.

$$P(R_h = i|X_i) = P(U_i > U_k) \tag{9}$$

$$= P(V(X_i, \beta) + \gamma_i > V(X_k, \beta) + \gamma_k) \tag{10}$$

$$= P(\gamma_k < \gamma_i + V(X_i, \beta) - V(X_k, \beta)) \tag{11}$$

Following the same approach as MC Fadden (1974)[35], we assume that γ_i are independently and identically distributed with Gumbel's law. Thus, the probability of

[8]For more details see Train (2003)

[9]In most cases, households use two types of energy sources but in this study we use the household main energy source.

choosing energy source i is then written:

$$P(R_h = i|X_i) = \frac{exp(\beta_i X_i)}{1 + \sum_{i=1}^{3} exp(\beta_i X_i)} \tag{12}$$

$$= \Lambda(X\beta) \tag{13}$$

Since we want to capture households' environmental sensitivity, fuel oil will be chosen as a reference category. This normalization will be realized by assuming $\beta_{fioul} = 0$. The relationship between two probabilities belonging to two alternatives is independent of the other alternatives. This hypothesis, known as the Independence of Irrelevant Alternatives (IIA) is a strong hypothesis of multinomial logit models. It is verified using the Hausman test and the Small-Hsiao test. The model estimation will be done using the maximum likelihood estimator. In linear regression models, the coefficients are interpreted directly as the explanatory variable marginal effect on the endogenous variable. However, this is not the case in generalized linear models. Indeed, the marginal effect of x_k on the dependent variable is given by:

$$\frac{\partial P(R_h = i|X_i)}{\partial x_k} = \Lambda(X\beta)[1 - \Lambda(X\beta)]\beta_k \tag{14}$$

However, considering that the energy source choice and the energy demand decisions are independent could lead to biased and inconsistent estimates (equation 8), because of the selection decision which is identified with the self-selection (Heckman, 1979) [25]. The demand for durable goods and their use are related decisions, and specifications that ignore this fact could lead to biased estimates (Dubin and MC Fadden, 1984) [16]. Similarly, Couture et al. (2012) [14] followed the same line and argued that the estimation of separate demand equations, without taking into account the endogenous decision on the type of wood use, would have resulted in biased estimations.

To obtain consistent estimates, this selection bias must be corrected in the demand equation (8). Thus several selection bias correction methods have been proposed since the Heckman studies (1979) [25]. Indeed, Lee (1983) [31], Dubin and MC Fadden (1984) [16], Dahl (2002) [15] have developed a generalized version of the Heckman model [25]. In this paper, the Dubin and McFadden method (1984) [16] will be used to take into account selection bias.

The Dubin and MC Fadden (1984)[16] approach, assumes a linear relation for the conditional expectation $E(\mu_i|\gamma_i)$, expressed in terms of γ_i.

$$E(\mu_i|\gamma_i) = \sigma\frac{\sqrt{6}}{\Pi}\sum_{i=1}^{I} r_i(\gamma_i - E(\gamma_i)) \tag{15}$$

Where r_i is the correlation coefficient between μ_i and γ_i, $Var(\gamma_i) = \frac{\Pi^2}{6}$ et σ^2 is the variance of μ_i.

The conditional demand equation can be estimated by taking into account the selection bias correction using equation (16):

$$q_i = \delta Z_i + \sigma\frac{\sqrt{6}}{\Pi}\sum_{k \mp i} r_k[s_k - s_i] + \eta_i \tag{16}$$

With $s_k = \frac{P_k ln(P_k)}{1-P_k}$, $s_i = -ln(P_i)$, η_i is the error term that is assumed zero mean. δ_i, σ, r_i, r_k, a set of parameters to be estimated [10].

3.2 Energy switching

As previously mentioned in Section 2, households can decide to change their sources before the end or after the end of the durable good life-time (heating system, etc.). The decision of whether or not to change sources is a binary variable (yes or no). Thus it can be understand as an utility maximization problem: the household changes its source if the utility of changing source (switching) is higher than not changing it ($U_{switch} > U_{no\_switch}$).

We assume that the utility of the household can be explained by several explanatory variables such as income, price, capital cost... (see Table 4):

$$U_{switch} = \alpha_{switch} H_{switch} + \xi_{switch} \tag{17}$$

$$U_{no\_switch} = \alpha_{no\_switch} H_{no\_switch} + \xi_{no\_switch} \tag{18}$$

[10] Assuming $r_1 + ... + r_n = 0$ in equation(9), Dubin and MC Fadden (1984)[16] reduce the coefficient number from i to i-1.

Let us assume that:

$$E_m^* = U_{switch} - U_{no\_switch} \tag{19}$$

the difference between the utility of changing the source and that of not changing the source. If it is positive, the household changes its source.
To simplify, we note H the vector of the explanatory variables, so we can write:

$$\begin{aligned} E_m^* &= \alpha_{switch} H + \xi_{switch} - \alpha_{no\_switch} H - \xi_{no\_switch} &(20)\\ &= (\alpha_{switch} - \alpha_{no\_switch})H + (\xi_{switch} - \xi_{no\_switch}) &(21)\\ &= \alpha_m H + \xi_m &(22)\end{aligned}$$

With $\alpha_m = \alpha_{switch} - \alpha_{no\_switch}$ et $\xi_m = \xi_{switch} - \xi_{no\_switch}$. According to (19) the household changes its source if $E_i^* > 0$. So, if we denote $E_m = 1$ if $E_m^* > 0$ and 0 otherwise we have :

$$\begin{aligned} P(U_{switch} > U_{no\_switch}) &= P(E_m = 1|H) &(23)\\ &= \frac{exp(\alpha_{switch} H)}{exp(\alpha_{switch} H) + exp(\alpha_{no\_switch} H)} &(24)\end{aligned}$$

4 Methodology and data

4.1 Data analysis

The French Agency for Environment and Energy Management (ADEME) every year carries out a national survey of energy used and the characteristics of households and dwellings. The data used in this study, except for the price [11], come from the surveys carried out between 2006 and 2011.
Household information was collected by means of a two-part questionnaire. The first part consists of 61 questions relating to the household characteristics, its heating

[11] Price data are collected in the "Pegase" database available on the website of the Ministry of the Environment, Energy and the Sea:
http: www.statistiques.developpement-durable.gouv.fr/ (last consultation 17/12/2015).
The emission factors were collected on the ADEME website:
url http://www.bilans-ges.ademe.fr/fr/accueil/authentification (last consultation 17/12 / 2015)

system, housing, the energy sources used, preferences and its choice on issues related to actions and policies (economic, environment, etc.) that the government should prioritize and the household's investments so as to improve the energy efficiency of its dwelling. For example, to determine households' energy choice and the quantity of energy consumed, we asked them to specify, from among a set of energy sources, their source for all uses (lighting, hot water, heating, appliances, etc.) and annual expenditure for this source. Using the same process, we construct the sensitivity variables (subjective and objective) in order to capture individuals' environment preference. Indeed, for the subjective sensitivity variable, we first ask the households to select from among twelve issues (related to pollution, unemployment, delinquency, lower taxes, etc.) the three they consider to be the most important. Secondly, participants were asked to choose from among eleven types of action relating to the environment in general (water management, prevention of industrial risks, household waste treatment, renewable energies development, etc.) the two that the government should implement as a priority. Thirdly, they were asked why they viewed one source as better than another, and to choose two out of seven reasons related to environmental sensitivity, cost, security and comfort. Contrary to the subjective sensitivity variable, the construction of the objective sensitivity variable is mainly based on the household's individual choice. Indeed, we are interested here in the three main reasons out of twelve that determine the household's choice of the energy source used for heating.

The second part of the survey contained questions about the type of work carried out, the capital cost[12] and the main reasons for this work[13]. It consists of 28 questions related to the conditions pertaining to carrying out the work, for example whether

[12]As a reminder, this represents the amount spent by the household to improve the energy efficiency of their dwelling.

[13]Here we specifically consider work concerning the initial installation of heating and/or water heating (except solar water heaters), replacement of heating and/or water heating with fuel change (except solar water heater), heating replacement and/or water heating without fuel change (except solar water heaters), initial solar water heating installation or replacement, initial heat pump installation or replacement.

or not the household benefited from a subsidy[14], a tax credit[15], or VAT reduction following the recent rate decrease from 19.6% to 5.5% for some items. The capital cost variable is observed only for individuals who changed their equipment. For individuals who had not changed their installation system, we calculated the capital cost by taking the average cost of the alternative to theirs [16]. However, we removed from the database all individuals who were not informed about the source used, and individuals who use collective central heating or urban network energy [17]. Moreover, we have some data missing in the income variable (around 3%). Thus, we can either eliminate those individuals or impute the missing data. We therefore thought it would be wisest to adopt the second alternative in order to limit information loss. To do this, we used an iterative imputation method based on the factor analysis mixed data (FAMD) algorithm recently proposed by Josse and Husson (2015) [27].

4.2 Descriptive statistics

Table 1 shows the proportion of households by type of energy used. In our database, more than three-quarters of the survey participants use electricity (49%) and gas (35%).

Wood consumption is very low, with less than 2% of households using it as an energy source. The rest of the households, about 14%, use fuel oil, which is the most polluting source in our database.

Energy prices increased between 2006 and 2011, but more so for electricity and wood (see Appendix). Indeed, electricity prices increased by 14% in recent years, while the price of wood increased slightly more, by 14.5%. For fuel oil, the average price is estimated at 7.1 euros /100kwh pci, while gas is estimated at 6.4 euros /100kwh

[14] it concerns PAH premium (Home Improvement Premium), ANAH subsidy (National Agency for the Improvement of Habitat), subsidy of the General Council, the Municipality or other subsidies....

[15] Since January 2005, people can claim tax credit on equipment and materials bought to reduce energy consumption (insulation, regulation, renewable energies, etc.)

[16] See section 4.2 for details

[17] Without information on the household energy source used, it is impossible to know their emission factor or its price

Table 1: Descriptive statistics

Variables	Wood 1.6%		Electricity 48.9%		Gas 35.24%		Fuel oil 14.26%	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Price[a]	3.6	0.1	15	0.7	6.4	1.8	7.1	1.1
Consumption[b]	616.8	382.1	955.5	539.0	968.7	493.9	1325	601.0
Observation	615		18854		13588		5500	

Source: ADEME, Ministry of Sustainable Development

Price in 100kwh pci, [b]energy consumption in kwh pci

pci, the price of which was most volatile during the period considered.
Although the proportion of electricity users is higher, energy consumption is on average higher for fuel oil users, at 1325kwh pci, more than double that of wood users. However, it should be noted that the distributions of energy consumption are very dispersed.

To reduce their consumption and improve energy performance, households carry out work, the total amount of which is termed "capital cost".

Table 2: Capital cost

Variables	Switch 10.80%			No switch 89.20%		
	2006/08	2009/11	Pooleed	2006/08	2009/11	Pooleed
Mean	2048.3	1667.3	1821.8	1499.4	1065.84	1254.3
Standart deviation	3023.1	1908.94	2425.5	2823.4	1209.51	2082.21
Observation	122	179	301	1080	1405	2485

We consider that the household has changed its source if it carries out work related to the initial heating installation or a heating replacement. On this basis, 10.80% of households in our database changed source and for which we only have the capital cost. For the remaining households, which did not change their source, we estimated their capital cost. For example, if the individual chose fuel wood, we consider the average of all other categories (electricity, fuel oil and gas capital cost).

The observed and estimated capital cost are presented in Table 2.
The observed capital cost average is less than 2000 euros in the overall period, while the estimated average capital cost is less than 1500 euros. However, like consumption distribution, capital cost distribution is highly dispersed, a fact that could be explained by the type of work, housing, etc.
Heating systems have the characteristics of durable goods and therefore have a long life-time, so the opportunities for households to change heating systems are very limited (Michelsen and Madelener, 2016) [36]. In Germany, for example, 47% of the residential heating systems were 15–21 years old and 16% were 22 years and older (Michelsen and Madelener, 2016) [36]. In the context of climate change and given residential sector energy consumption and the contribution of CO_2 emissions, households need to be more aware of environmental issues, particularly energy production and consumption. Indeed, Figure 2 shows that households implicitly declare they have an environmental preference, but when choosing their source they base their decision on other factors such as energy source cost, etc.

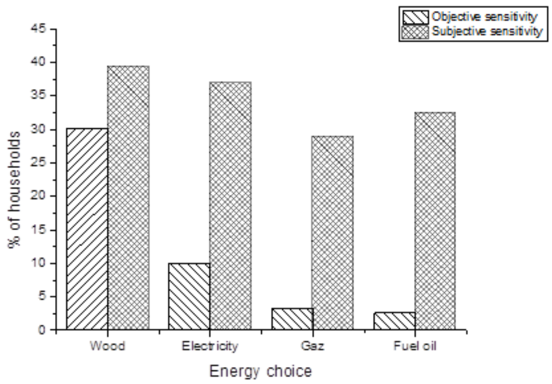

Figure 1: Proportion of households environment sensitive

For subjective sensitivity, the proportion of households is greater than 30% for all sources, but if we look at objective sensitivity, which indicates whether or not people take the environment into account in their energy source decision, the proportion of households is relatively low, about 10% for those that use electricity and less than 4% for those that use gas and fuel oil.
The discrete/continuous model has thwo dependent variables. The first is the energy

source choice, which is a qualitative variable with four modalities. Individuals can choose wood, electricity, gas or fuel oil. The second dependent variable is energy consumption, which is a continuous variable. Average consumption is estimated at 11507.69 kwh pci. The third dependent variable used in this paper is a binary variable that describes energy switching.

Table 3: Dependent variables

Variables	Variable description	Scale	%
Energy choice	The househod energy use	1 = Wood	1.6%
		2 = Electricity	48.9%
		3 = Gas	35.24%
		4= Fuel oil	14.26 %
Demand	The quantity of energy consumed by the households	Mean	SD
		11507.69	8124.86
Energy switching	This variable describes weather the households changed or not his energy source	1 = switching	10.80 %
		0 = otherwise	89.20%

The independent variables, of which there are ten, can be grouped into three categories: economic variables (income, energy source price, capital cost), environmental variables (objective sensitivity, subjective sensitivity and source emission factor) and control variables (house owner, dwelling, subsidy and period). The house size variable was removed for collinearity reasons.

Table 4: Independent variables

Variables	Variables description	Scale	%
Income	Households annual income Y in euro, coded from 1 to 11	1 if < 7700	3.96%
		2 = 7700 to 12200	5.56%
		3 = 12201 to 15700	8.22%
		4=15701 to 19000	9.19%
		5=19001 to 23000	12.96%
		6= 23001 to 27200	13.61%
		7= 27201 to 31700	15.25%
		8= 31701 to 36600	12.67%
		9=36601 to 43800	10.21%
		10= 43801 to 56300	4.89%
		11 if > 56300	3.48%
Objective	The households take into account or not to the environment in his energy source decision	Binary (yes;no)	33.45%
Subjective	The household declare to have an environnemental prefernce	Binary (yes;no)	6.76%
Owner	The household is the homeowner	Binary (yes;no)	61.83 %
Subsidy	the household received a subsidy	Binary (yes;no)	7.31%
Dwelling	Apartment or studio	Binary (yes;no)	27.31%
Price	Energy prices in euro	Mean	SD
	(100kwh pci)	10.7	4.43
Capital cost	Total amount spent on work in euro	1315.6	2128.8
Emission factor	Energy source CO_2 emission in kg co_2eq	0.17	0.10

50% of households have annual incomes less than 26,120.17 euros. A quarter of individuals' (low income) earn less than 18,306.17 euros by year, while the 25% (high income) earn more than 34,117.63 euros . For more details of other independent variables, see Table 4.

5 Results and interpretations

The models' estimations are presented in this section. We first present the multinomial logit model estimates so as to understand the factors that determine households' energy choices. We then come to the demand equations estimates and finally the results of the energy switching model.

5.1 Energy Consumption

5.1.1 Choice model estimation

Table 5 provides the choice model estimates obtained using the method proposed by Dubin and McFadden (1984) [16]. Note that fuel oil is used as a reference category, so that the estimated coefficients can be interpreted with regard to this category. The choice model specification is based on the variables shown in Tables 3 and 4. We added temporal dummies to capture the years' fixed effect. However, since two variables describe the household's environmental sensitivity, we carried out the estimates by considering objective sensitivity (model 1) and subjective sensitivity (model 2).

Given the results of the multinomial logit model's estimates of marginal effects, it appears that income has a significant effect on energy choice. Indeed, the estimated coefficients are all significantly different from zero, but the coefficient associated with the choice of wood is negative (this result is in line with that obtained by Couture and al. (2012) [14]. Analysis of marginal effects shows that a low income increases the probability of choosing wood, while a high level of income leads to the choice of electricity and gas rather than fuel oil. Environmental preference influences households' energy choice. Thus, the estimated coefficients of the objective and subjective sensibility variables related to wood and electricity choices are positive and significant. The objective sensitivity variable increases the probability of choosing wood by 0.33 percentage points and of choosing electricity by 6.74 percentage points. For the subjective sensitivity variable, these marginal effects are estimated at 3.36 and 26.64 percentage points for wood and electricity respectively. This result suggests that individuals who have a preference for the environment will tend to choose wood

Table 5: Multinomial logit model marginal effects estimation

	Wood		Electricity		Gas	
	(1)	(2)	(1)	(2)	(1)	(2)
Income	-0.0011^{***}	-0.0008^{***}	0.0021^{*}	0.0037^{***}	0.0036^{***}	0.0020^{**}
	(0.0002)	(0.0002)	(0.0011)	(0.0011)	(0.0010)	(0.0010)
Objective	0.0033^{***}		0.0674^{***}		-0.0712^{***}	
	(0.0010)		(0.0055)		(0.0052)	
Subjective		0.0336^{***}		0.2664^{***}		-0.2036^{***}
		(0.0038)		(0.0089)		(0.0080)
Homeowner	0.0034^{***}	0.0002	-0.0105^{*}	-0.0328^{***}	-0.0129^{**}	0.0051
	(0.0011)	(0.0011)	(0.0062)	(0.0062)	(0.0059)	(0.0059)
Type of dewelling	-0.0179^{***}	-0.0155^{***}	0.1147^{***}	0.1257^{***}	0.0303^{**}	0.0175^{***}
	(0.0010)	(0.0010)	(0.0061)	(0.0061)	(0.0059)	(0.0059)
2008/2009	0.0041^{***}	0.0048^{***}	-0.0036	0.0110	0.0041	-0.0099
	(0.0014)	(0.0013)	(0.0067)	(0.0067)	(0.0064)	(0.0064)
2010/2011	0.0045^{***}	0.0048^{***}	0.0277^{***}	0.0371^{***}	-0.0066	-0.0159^{**}
	(0.0014)	(0.0013)	(0.0065)	(0.0065)	(0.0063)	(0.0062)

	Modèle 1	*Modèle* 2
Observation	38557	38557
Log-likelihood	-39940.25	-39458.843
LR test x^2	1950.86	2913.67
P-value	0.0000	0.0000

The standard deviations are in parenthese. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

or electricity, which has a lower emission factor and is therefore more environmental friendly than fuel oil. However, we detect a contrary effect in the case of gas.

As well as these factors, the type of dwelling and whether the householder is a homeowner or tenant affects the choice of energy. The results show that if the householder is the homeowner, the probability of choosing wood increases and that of electricity or gas decreases. In addition, if the dwelling is an apartment or a studio, it is more likely that the household uses electricity or gas rather than fuel oil, compared to those living in single-family homes. However, the use of wood is less favored if the household lives in an apartment or studio rather than in a single house (this result is consistent with that of Couture et al. (2012) [14]).

The periods 2008/2009 and 2010/2011 seem to be more favorable to the wood and electricity choices than the period 2006/2007. This trend marks a favorable dynamic towards an energy transition, and its improvement could contribute to decision-makers aim to reduce CO_2 emissions by a factor of four by 2050.

5.1.2 Estimation of demand equations

Since energy demand is determined by the energy choice, the demand equations estimation is done in two steps, as in Dubin and McFadden (1984)[16]. In the first step, we estimate the discrete model using the maximum likelihood method and construct the selection bias correction terms for each alternative. In the second step, these correctors are introduced into the demand equations. The estimates are presented in Table 6, considering four specifications. The fundamental difference between these models can be found in the continuous model. Thus models 1 and 2 are constructed taking into account the objective and subjective variables solely in the discrete model. For specifications 3 and 4, these variables are introduced respectively in the two steps of the discrete/continuous model.

Some of the coefficients associated with the selection bias correction terms are significant. This finding suggests that taking into account the two choices (discrete and continuous) simultaneously seems to be necessary to avoid the problems of bias and non-convergence of the estimators.

The 2008/09 and 2010/11 periods are dummy variables introduced to capture the unobserved heterogeneity with 2006/07 as the reference period.

The income effect is not significant on wood demand. In contrast, income has a positive impact on electricity and gas demand. Coefficients of electricity demand relative to income range from 0.0348^{***} to 0.4637^{***} and those of gas from 0.0294^{***} to 0.0443^{***}.

Energy demand price elasticities are all negative and significantly different from

Table 6: Demand equation estimation results

	Wood				Electricity				Gas			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Income	0.0290	0.0419	0.0296	−0.1511	0.0348***	0.4637***	0.0406*	0.0352***	0.0352***	0.0294***	0.0309***	0.0443*
	(0.0371)	(0.0285)	(0.0287)	(0.4377)	(0.0038)	(0.0041)	(0.0221)	(0.0108)	(0.0057)	(0.0046)	(0.0102)	(0.0254)
Price	−2.3942**	−1.1345	−2.4321**	−1.5533*	−1.3331***	−1.3545***	−1.3344***	−1.3383***	−1.2238***	−1.2218***	−1.2241***	−1.2220***
	(1.0776)	(0.7990)	(0.9750)	(0.8553)	(0.2580)	(0.3195)	(0.2809)	(0.2758)	(0.0701)	(0.0584)	(0.0618)	(0.0587)
Objective			−0.0362				−0.2225				0.4317	
			(0.5028)				(0.7623)				(0.5220)	
Subjective				4.2526				2.9921***				3.7426
				(5.5274)				(1.0100)				(4.0522)
Homeowner		−0.0312			0.0391*	−0.0104	0.0214	−0.1760***	0.0207	0.0400*	0.0234	−0.2270
		(0.0986)			(0.2051)	(0.0200)	(0.0709)	(0.0716)	(0.0272)	(0.0212)	(0.0545)	(0.3084)
Type of dewelling	1.2099	−10.0274	0.8158	−3.6586	−0.6300***	−0.2887***	−0.6522***	−0.1875*	−0.0385	−0.2175*	0.2829	0.6637
	(0.6748)	(0.8171)	(0.8339)	(14.3431)	(0.1068)	(0.0934)	(0.1419)	(0.1040)	(0.1453)	(0.1050)	(0.4041)	(0.9552)
2008/2009		1.6439		0.9894	0.0675***	0.0823***	0.0803	0.2309**	0.1815***	0.1815***	0.1656***	0.3199
		(2.5375)		(2.6550)	0.0211)	(0.0207)	(0.0823)	(0.0979)	(0.0215)	(0.0157)	(0.0483)	(0.1982)
2010/2011		1.1459		1.0161	0.0927**	0.1507***	0.0520***	0.4460***	0.2549***	0.2201***	0.3763***	0.5830***
		(1.7835)		(2.2226)	(0.0418)	(0.0413)	(0.1658)	(0.1047)	(0.0406)	(0.0190)	(0.1617)	(0.3919)
Constant	14.1117***	12.8143	14.1257***	3.0882	12.1657***	12.3300***	13.5827***	6.0229***	11.9414***	11.3591***	14.6543***	17.2433***
	(2.4219)	(1.8844)	(1.9438)	(28.0663)	(0.6960)	(0.8357)	(4.9214)	(3.3195)	(0.3283)	(0.2569)	(3.3433)	(92.0969)
$m(p_1)$					−0.0671	0.4693	−0.2910	2.06230***	−0.4452	0.0721	−0.4482	−0.5266
					(0.5369)	(0.3462)	(0.9508)	(0.8033)	(0.6563)	(0.5201)	(0.7561)	(0.9020)
$m(p_2)$	0.0929	1.0514	−1.1984	1.7212					1.4281***	0.4425	3.9662	6.2016
	(1.0495)	(1.2588)	(4.9898)	(18.0127)					(0.3693)	(0.4839)	(3.7818)	(6.8240)
$m(p_3)$	−1.1438	−2.0169	−0.2047	−1.0522	0.3681	−1.3354***	−0.1414	1.1480	−1.0537*	0.7074***	−2.1095	−2.8110
	(1.3651)	(1.487)	(1.7868)	(3.6719)	(0.4846)	(0.2606)	(1.8897)	(1.0762)	(0.5807)	(0.2481)	(1.6188)	(2.4515)
$m(p_4)$	0.4249	1.3480	0.7715	−2.5573	−0.2019	1.0401***	1.3899	−6.6002**				
	(1.0436)	(1.7695)	(5.6459)	(23.1552)	(0.2434)	(0.3069)	(5.5855)	(3.3202)				
σ^2	0.67133	5.9216	1.0926	12.8073	0.4682	2.5658**	2.1338	41.7324	3.0441	0.8082	18.4642	42.5373
	(18.1621)	(11.0782)	(181.3358)	(66.2510)	(0.5186)	(1.0421)	(52.9777)	(29.0743)	(1.8676)	(0.6269)	(27.5078)	(92.0969)
Proba	0.0532	0.0164	0.0873	0.0324	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Termes m(P1), m(P2), m(P3),m(P4) are the selection bias correction terms. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

zero, but those associated with wood prices are higher in terms of absolute value. This result suggests that energy prices appear to be a determinant factor for energy demand fluctuation and that it has more impact on wood demand than on other energy sources. However, the price elasticities are very high compared to those obtained by Couture et al (2012)[14], though those relating to electricity are similar to the elasticities obtained by Bernard et al. (2011) [8] for Quebec households. The variability of the estimated parameters reflects the type of data used to estimate energy demand (time series, cross-section or Panels data), the period considered and the geographical area. Similarly, model specification and estimation methods contribute to a large extent to the estimated parameters (Bernard et al., 2011) [8]. Energy demand variability can also be explained by other factors that are specific to the household or its dwelling. For example, individual houses consume more electricity, a finding that could be explained by the fact that they often have a larger surface area than apartments (a large area requires more energy for heating than a small area). However, it should be noted that models 1 and 2 only take into account environmental variables on the choice models and not on the demand equations. Thus these variables are introduced in equation (16) to appreciate their implications for household consumption behavior (model 3 and 4). For the objective variable, the estimated coefficients have the expected signs for wood and electricity, but they are not significant. In contrast, for electricity the coefficient associated with the subjective variable is significant and positive. These individuals declare themselves sensitive to policies and problems related to environment, but their consumption does not decrease. Indeed, energy demand is a derived demand that depends on the set of appliances owned by the household (Carter et al., 2012) [13]. In addition, environmental considerations influence energy choice more than energy demand, which is often conditioned by random factors such as climate (heating) or simply needs related to cooking, etc.

5.2 Energy switching

In this section, we present the energy switching results. Since our data are cross-sectional and are observed over several years on different individuals, we can not use the panel data model. We therefore divided our sample into two sub-samples (2006-2008 / 2009-2011), and dummy variables are introduced to capture the temporal effect. Thus estimates of these sub-samples and the overall sample were obtained by considering the objective sensitivity variable (model 1) and the subjective sensitivity variable (model 2). This approach allows us to capture the differences that may exist on the estimated coefficients in the two sub-periods.

5.2.1 Economic variables

We find that income and capital cost are the economic variables that explain households' energy switching. Indeed, income has a positive and significant effect on the probability of switching. The value of the marginal effect is estimated at 0.0129*** and 0.0130*** for the first period respectively for model 1 and model 2 and 0.0074*** for the second period for these two models. For all the periods considered, high income individuals are more likely to switch than low income individuals. However, the influence of capital cost on the probability of switching is negative. The value of the marginal effect, associated with the relative capital cost $K_{i|j}$ (where j is the energy with the lowest capital cost), is between -0.0018*** and -0.0015*** for all the periods considered. For example, in the first period, an increase in the relative capital cost of a unit reduces the probability of switching by 0.0016.

Relative energy price does not seem to have an effect on households' energy switching. Adoption of a new heating system that is more energy efficient increases the budget allocated to energy consumption in the short term and reduces the purchasing power of other goods. Thus the attitude of lower income individuals can be explained by the fact that they have less flexibility to implement these changes than high income individuals. Similarly, the negative effect of the capital cost on the probability of switching seems to be reasonable. Indeed, a heating system replacement requires taking into account both the initial investment for renovation and the user-cost (Ademe, 2016)[3], which seems to be sufficiently high to constrain households to adopt an energy saving approach that can save up to 20%, according to Ademe [3]. Similarly, Michelsen and Madelener (2016)[36] consider that maintenance costs and heating system maintenance and repair are the main drawbacks of

Table 7: Energy switching

	2006/2008		2009/2011		Pooleed	
	(1)	(2)	(1)	(2)	(1)	(2)
Income	0.0129***	0.0130***	0.0074**	0.0074**	0.0116***	0.0117***
	(0.0039)	(0.0039)	(0.0030)	(0.0030)	(0.0023)	(0.0023)
Price	0.0026	0.0024	0.0117	0.0120	0.0085	0.0088
	(0.0106)	(0.0107)	(0.01055)	(0.01059)	(0.0075)	(0.0075)
Capital cost	−0.0016***	−0.0016***	−0.0018***	−0.0017***	−0.0015***	−0.0015***
	(0.0003)	(0.0003)	(0.0005)	(0.0005)	(0.0002)	(0.0002)
Emission	0.0035	0.0033	0.0021	0.0021	0.0025	0.0025
	(0.0035)	(0.0035)	(0.0039)	(0.0021)	(0.0026)	(0.0026)
Objective	0.0073		0.01106		0.0122	
	(0.0178)		(0.0152)		(0.0115)	
Subjective		−0.0205		0.0034		−0.0039
		(0.0245)		(0.0256)		(0.0184)
Subsidy	0.0194	0.0201	0.0238	0.0239	0.0191	0.0194
	(0.0261)	(0.0292)	(0.02925)	(0.0292)	(0.0198)	(0.0198)
Type de log.	−0.0303	−0.0318	0.04267**	0.0537**	0.0211	0.0207
	(0.0223)	(0.0218)	(0.02879)	(0.02894)	(0.0181)	(0.0182)
2007	−0.2789***	−0.2814***			−0.1436***	−0.1427***
	(0.0518)	(0.0526)			(0.0124)	(0.0124)
2008	−0.7652***	−0.7733***			−0.2789***	−0.2760***
	(0.0878)	(0.0873)			(0.0313)	(0.0311)
2009					−0.2637***	−0.2605***
					(0.0298)	(0.0294)
2010			0.0134	0.01239	−0.1962***	−0.1949***
			(0.0340)	(0.03394)	(0.0198)	(0.0197)
2011			0.3581***	0.3535***	−0.1073***	−0.1064***
			(0.0726)	(0.0721)	(0.01136)	(0.0114)
Observation	1202	1202	1553	1553	2755	2755
Log-likelihood	−334.5181	−334.3131	−504.9730	−505.2679	−840.2419	−840.7902
LR test x^2	120.34	120.75	87.77	87.18	207.60	206.51
P-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pseudo R^2	0.1525	0.1530	0.0800	0.0794	0.1100	0.1094

*** Significatif à 1%, ** Significatif à 5%, * Significatif à 10%.

wood pellet-fired boilers.

5.2.2 Environment variables

Household environmental sensitivity is taken into account by objective sensitivity variables (the household declares it takes into account the environment in the energy choice decision) and subjective sensitivity variables (households declare they are concerned about environmental policies and problems). As well as these variables, there is the energy source emission factor (Table 8).

Table 8: Emission factors

Fuel	CO2 equivalent (Kg /MWh)
Wood log 20%	0.0295
Electricity	0,0840
Fuel oil	0,3240
Butane, propane	0.2600
Natural gas	0.2430

Source: ADEME

In terms of emission factors, wood is the cleanest source followed by electricity. These two types of energy are used by more than 50% of households, with 49% for electricity, suggesting a certain preference for electricity. Fuel oil is the most polluting source in our database (with an emission factor of 0.3240 kgCO2e/kwh). The proportion of households using this energy source is about 14%, seven times that of households using wood. However, the marginal effects of objective and subjective variables are all non-significant for all periods. Similarly, the energy emission factor has no effect on the probability of switching. This suggests that household energy switching is not motivated by ecological concerns.

Thus greenhouse gas emissions related to the energy sector account for about two-thirds of all anthropogenic greenhouse gas emissions. CO2 emissions related to this sector have increased over the past century to higher levels (IEA, 2015)[29]. It is therefore essential to implement action to provide incentives to reduce energy consumption by improving energy efficiency.

5.2.3 Control variables

The control variables used in this study are the type of dwelling and subsidy. The homeowner variable was not chosen because it does not vary (energy switching is predominantly carried out by homeowners).

The results show that only the type of dwelling impacts on the probability of switching. Indeed, between 2006 and 2008, households living in individual houses were more likely to switch sources than those living in apartments (or studios), but the effect is not significant. In contrast, for the period 2009-2011, there is a significant effect: energy switching was more implemented in apartments and studios than in individual houses.

Other characteristics related to the dwelling, such as house size, can influence the household decision. Thus Michelsen and Madelener (2016)[36] find a significant and positive effect of size on the probability of switching in Germany. They explain this result by the fact that large homes have more space for storing wood pellets. Similarly, people who have large houses are more likely to invest in insulation (Nauleau, 2012) [42]. The coefficient associated with subsidy has positive but not significant effect on the probability of switching. It would be interesting to assess the impact of other control variables, such as tax credits and VAT reductions, introduced by the authorities to encourage the green energy choices, but our data are insufficient to include them in this analysis. However, Nauleau (2012) [42] finds a positive impact of tax credits (CIDD) on investments in energy efficiency (insulation) after a latency period of two to three years.

6 Conclusion

Understanding the factors that drive households' energy consumption, as well as their decision to switch to cleaner energy sources, is vital for shifting public policies and orientations toward a more efficient and environmental friendly energy system. Our paper focuses on these aspects, highlighting how environmental sensitivity motivates their transition to less polluting sources. To this end, our empirical approach is based on a discrete/continuous model for analyzing energy consumption and a binary logit model for analyzing households' energy switching. Since the amount of energy consumption is linked to energy choices, the omission of this relation could introduce a selection bias. For this reason we use the two-steps method proposed by McFadden (1984).

First, we determine factors influencing the choice of energy source. We show that lower-income households are more likely to choose wood as their main energy source, while a higher income leads to the choice of electricity and gas. In addition, environmental preferences, captured here by objective and subjective variables, influence the household's choice. Indeed, when a household explicitly takes into account the environment when choosing its energy source, the probability of choosing wood increases by 0.33 percentage points and of choosing electricity by 6.74 percentage points. When the household considers that environmental issue are more important or that the government priority should be to promote renewable energies and fight against global warming, these marginal effects are estimated to rise to 3.36 and 26.64 percentage points for wood and electricity respectively. However, these variables have a negative impact on the gas choice. Households' energy choice also depends on the variables related to dwelling characteristics, such as the type of dwelling and owner-or-tenant status.

Second, regarding the determinants of energy demand, their impacts vary from one source to another. Income has no effect on wood demand but positively and significantly influences electricity and gas demand. Price elasticities associated with the different sources are all negative and significantly different from zero. Prices seem to explain well fluctuations in energy demand, but its variation impacts more on wood demand. A possible explanation is the existence of a substitution effect between wood and other energy sources (gas, electricity and fuel oil). However, environmental variables have no effect on households' energy consumption. Indeed, environmental considerations have more effect on the energy choice than on consumption, which is often determined by factors such as climate (heating), requirements for cooking or simply by the household's set of appliances.

Third, households' energy switching is largely influenced by income and the relative capital cost. Higher-income households are in general more likely to switch than lower-income households, while the influence of relative capital cost on the probability of switching is significantly negative. For example, from 2006 to 2011, an increase of one unit in the relative capital cost reduces the probability of switching approximately by 0.0015. Relative energy prices seem to have no effect on households' energy switching. Similarly, environmental preferences and GHG emission factors are not significant. This suggests that the households' energy switching is not motivated by ecological concerns. Moreover, subsidy has no effect on energy switching, and energy switching was more frequent in apartments and studios than in individual houses between 2009 and 2011.

Annexe

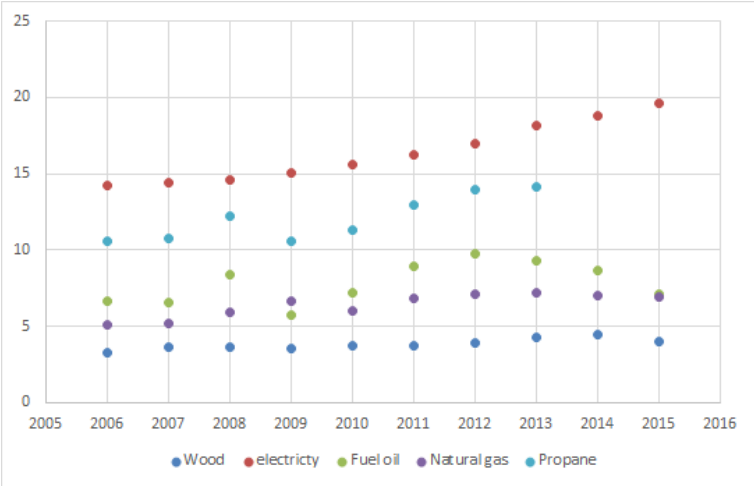

Figure 2: Evolution of energy prices

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