Fuel poverty in France: affected groups and their sensitivity to energy price fluctuations

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Abstract

In this paper, we aim to discuss characteristics of fuel poor households in France and to analyze their sensitivity to energy prices fluctuations.

To this end, we start in the first part of the paper by presenting a critical review dealing with poverty definitions and measures based on which we calculate and discuss fuel poverty rates in France. Then, after identifying groups of affected households, we propose a qualitative approach based on three complementary methods namely Multiple Correspondence Analysis (MCA) and Hierarchical and Partitioning Clustering Analysis (HPCA) in order to identify their common characteristics. Within this framework, we highlight the difficulty of identifying and drawing a "*profile-type*" of fuel poor household in the perspective of implementing public policies, and we detail, as a consequence, characteristics of some selected representative fuel poor households.

In the second part of the paper, we focus on estimating households own price elasticities of energy demand by using a panel threshold regression model. The original dimension of this model is that it permits to take into account plausible non-linearities in the energy demand function that can be induced by the income level. These non linearities give rise to the identification of different groups of households reacting differently to price variations according to their income level. Results show that we can identify two heterogeneous groups of households and that the fuel poor households belong mostly to the group of households which have the highest price elasticity.

Based on these findings, some policy recommendations are suggested.

Keywords

Fuel poverty, Affected groups, Price elasticities, Panel threshold regression model, France.

JEL classification

Q_{41}; Q_{48}; G_{58}; C_{21}; C_{22}

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1   Introduction

In 2008, the European Union (EU) has been committed under the so-called climate and energy package to reduce for 2020 by 20% its greenhouse gas emissions with respect to their level of 1990, to improve by 20% its energy efficiency and to rise to 20% the share of renewable energies in total energy consumption. In the beginning of 2014, the EU has proposed the 2030 policy framework for climate and energy which supports and extends the climate and energy package. In particular, for 2030, it aims to reduce domestic greenhouse gas emissions by 40% below the level of 1990, to improve by 30% the energy efficiency and to increase to at least 27% the share of renewable energy in total energy consumption [3].

At national level, to be in line with EU energy and climate objectives, the French Government sets out within the framework of The Act of 17 August 2015 on Energy Transition for Green Growth medium and long-term objectives for national energy policy. This policy seeks to enhance energy autonomy, decrease greenhouse gas emissions, and provide necessary tools to stakeholders to boost green growth. In particular, it establishes 6 objectives:

— contribute to the target of a 40% decrease in EU emissions by 2030 [4],
— lessen national consumption of fossil fuels by 30% by 2030,
— reduce the share of nuclear energy in electricity production to 50% by 2025,
— increase the share of renewable energies in final energy consumption and in electricity production to, respectively, 32% and 40% by 2030,
— halve national final energy consumption by 2050 [4],
— cut waste going into landfills by 50% by 2050.

Within the same framework, to induce behavior change and support energy transition, the French Government has decided to price the carbon at 56€ per tonne by 2020 and 100€ by 2023.

Given the ambitious character of these objectives, and in order to ensure social acceptability and smooth occurrence of energy transition, the French Government has incorporated in The Energy Transition Act a social component calling for the prevention of fuel poverty problem [5], a situation under which households experience serious difficulties to meet their energy needs [6]. Indeed, currently in France, ONPE (2016) estimates the number of fuel poor households to 3.8 millions. With the expected diffusion of renewable energies under the impulsion of The Energy Transition Act, it is plausible that the cost of energy will increase and the conditions of access to energy will change. As a consequence, some groups of population could find it difficult, even impossible, to satisfy their energy needs. In this context, it is important to ensure that the implementation of objectives of The Energy Transition Act will not exacerbate fuel poverty problem.

To avoid the prevalence of fuel poverty situations, the French Government has put in place several short and long-term measures and continues carrying reflexion on the issue. In particular, it has implemented curative measures aiming to help fuel poor households to pay their energy bills, *i.e.* income support, affordable fuel pricing, and assistance with solvency in the event of arrears. It has also implemented preventive policies which, rather, focus on the improvement of dwelling energy efficiency, *i.e.* dwelling insulation, double glazing, etc... [7]. The recognition of these measures as tools to fight fuel poverty was usually associated with debates about their efficiency.

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3. The EU precises that this European objective will not be declined to national objectives. Indeed, the EU aims at giving the 28 member states flexibility to transform their energy systems in a way which takes into account specificities of national contexts.

4. Compared to 1990 level.

5. This social component also includes a target of "zero waste".

6. Detailed definition of fuel poverty are discussed in section 2.1.

7. Different measures to fight fuel poverty are presented in more details in section 5

Dwelling renovation measures, although recent in France, seem to be a more promising strategy to resolve fuel poverty problem in a lasting way.

Upstream to discussions about the efficiency of different measures to fight fuel poverty, debates have always focused on the crucial character of reliable identification of fuel poor households and the detailed description of their profiles. In fact, the multidimensionality of fuel poverty concept makes difficult pursuing these tasks. It is a concept whose understanding calls for jointly analyzing three dimensions namely the socio-economic situation of the household mainly his income level, his conditions of access to energy including the impact of energy prices variations, and characteristics of his dwelling, in particular, in terms of energy efficiency.

By focusing on these three dimensions of the fuel poverty problem, we seek two objectives in this article. First, based on existing fuel poverty measures, and by taking into account characteristics of the household and of its dwelling, we aim to identify and draw the profile of groups of fuel poor households in France. Second, we propose to analyze how the household income impacts its reaction to energy prices variations, given its other social and dwelling characteristics. In particular, we aim to compare the sensitivity of fuel poor and non fuel poor households to energy prices variations.

The paper is structured as follows. In section 2, we give a brief review of fuel poverty definitions and measures. In section 3, we propose a qualitative multidimensional analysis aiming at drawing the profile of fuel poor households. At this end, we start by determining groups of fuel poor households according to two expenditures-based measures namely the 10% and the "Low Income High Cost (LIHC)" indicators. Then, we run a Multiple Correspondence Analysis (MCA) under which we discuss characteristics of fuel poor households. By extension, we also perform a Hierarchical and Partitioning Clustering Analysis (HPCA) to classify fuel poor households having similar characteristics in homogeneous groups. In section 4, we focus on analyzing the sensitivity of fuel poor households to energy prices fluctuations. We use a Panel Transition Regression (PTR) model which permits to take into account plausible non linearities in households reactions, induced by the level of their respective income. In section 5, we mainly discuss policy implications of our results, within the framework of the French fuel poverty context. Finally, in section 6 we give some concluding remarks.

2   A brief review on fuel poverty definitions and measures

We aim in this section to discuss existing definitions and associated measures of fuel poverty. We start in subsection 2.1 by focusing on the French and United Kingdom (UK) definitions and stress the pioneering position of UK in tackling the problem of fuel poverty. Then, we propose in subsection 2.2 a quick review of literature which classifies measures into homogeneous families and summarizes their advantages and drawbacks.

2.1   Fuel poverty definitions

From a general point of view, the fuel poverty refers to a multidimensional concept under which three phenomena are nested namely the socio-economic situation of the household mainly the income level, the characteristics of the dwelling including its energy efficiency, and the energy access conditions mostly the price of energy (EPEE (2006), Devalière (2007), Palmer et al. (2008), Blavier et al. (2011)). Therefore, a household is considered as fuel poor when he occupies an energy inefficient dwelling and is unable to pay the bill for heating his home at an appropriate standard

level of warmth [8].

In line with this general presentation of the fuel poverty, an official definition of fuel poverty was stated in France by the Act number 2010-788 of July 12, 2010 dealing with environment national commitment ("Loi Grenelle 2") and amending the Act number 90-449 of May 31, 1990 aiming at implementing French housing rights ("Loi Besson") [9]. According to this definition a fuel poor household represents a person who has difficulties inside his dwelling to have access to energy to satisfy his basic needs because of insufficient financial resources [10], *i.e.* low income, or because of dwelling characteristics [11], *i.e.* energy inefficiency, presence of damp and rot.

Although giving an official general framework for defining fuel poor households, the French definition of fuel poverty is still non practical. Indeed, it does not establish any clear-cut scientific or even operational criteria, that is, a set of indicators, to ensure a clear identification of fuel poor households and reliable definition of necessary policies to fight the fuel poverty (Host et al., 2014). By the same, at the European scale, the European Union (EU) has not yet adopted a common definition of fuel poverty nor common indicators permitting to measure it [12]. When separately considering EU countries, only UK Government has recognized the phenomenon of fuel poverty as a social and sanitary issue and defined, as a consequence, a measurable indicator to quantify it.

The fuel poverty concept was in essence born in the UK in the 1970s under the leadership of activist organizations which acted in a way to put attention of authorities and population on the winter mortality phenomenon induced by the steady growing of energy prices preventing some households to heat their dwellings at an appropriate standard level of warmth [13] (Dutreix et al. (2014), ONPE (2014), ONPE (2015)). Two decades after that, on the basis of Boardman (1991), it is only in 2001 within the framework of the 2001 UK Fuel Poverty Strategy that a quantitatitive indicator has been defined to mesure fuel poverty magnitude [14]. According to this indicator a household is fuel poor when its heating expenditures to maintain an appropriate level of warmth [15] are greater than 10% of its income [16].

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8. According to the World Health Organization (WHO), an appropriate standard level of warmth is defined as $21°C$ for the main living area and $18°C$ for other occupied rooms (ONPE, 2015).

9. La "Loi Besson" number 90-449 of May 31, 1990 stipulates that anyone encountring difficulties, particularly because of inadequate financial resources or living conditions, can benefit from the support of the community according to the rules displayed in the following Act to have access to a decent and independent housing ensuring water, energy, and telephone access - Traduced from French "*Toute personne éprouvant des difficultés particulières, en raison notamment de l'inadaptation de ressources ou de ses conditions d'existence, a droit à une aide de la collectivité, dans les conditions fixées par la présente loi, pour accéder à un logement décent et indépendant ou s'y maintenir et pour y disposer de la fourniture d'eau, d'énergie et de services téléphoniques*" (JORF, 1990).

10. We note that in France, the poverty threshold below which a household is considered to be poor is 60% of the median national income (INSEE, 2014).

11. Traduced from the French written Act number 2010-788 of July 12, 2010 according to which "*est en situation de précarité énergétique au titre de la présente loi une personne qui éprouve dans son logement des difficultés particulières à disposer de la fourniture d'énergie nécessaire à la satisfaction de ses besoins élémentaires en raison de l'inadaptation de ses ressources ou de ses conditions d'habitat*"(JORF, 2010).

12. We nevertheless note that within the framework of the European fuel Poverty and Energy Efficiency (EPEE) project conducted between 2006 and 2009 a descriptive approach to analyze fuel poverty in some European countries, *i.e.* Belgium, France, Italy, Spain and United Kingdom, has been used. It is based on three criteria which are the ability to pay to keep one's home warm, the existence of dampness, leaks, mould in the dwelling, and arrears on electricity, gas and water bills (EPEE, 2006).

13. *Cf.* footnote number [8].

14. According to Fahmy et al. (2011) "*the Warm Homes and Energy Conservation Act, effective from November 2000 and introduced with cross-party support, represents the first formal acknowledgement of fuel poverty as a social policy issue requiring governmental intervention. This Act mandated the UK Government and Devolved Administrations to develop and implement a strategy for fuel poverty reduction, resulting in the 2001 UK Fuel Poverty Strategy. This official document committed the UK Government and Devolved Administrations for the first time to the ambitious goal of eliminating fuel poverty (DETR, 2001). Fuel poverty reduction targets include eliminating fuel poverty in England amongst "vulnerable" households by 2010, i.e. older persons, sick and disabled households and families with children, and amongst all households by 2016. These targets were reaffirmed in the 2007 Energy White Paper DTI (2007), and broadly similar targets are in place within the Devolved Administrations (DSDNI (2004), Scottish Executive (2002), WAG (2003))*".

15. *Cf.* footnote number 8 for a standard definition of an appropriate level of warmth.

16. *Cf.* subsection 2.2 or table A below for more details about the 10% indicator.

Nevertheless, this expenditures threshold is currently obsolete. In fact, it represents the double of median of energy expenditures observed in UK during the budget survey of 1988. From this date, this threshold was not updated nor revisited to become more suitable with current trends. As a consequence, today, fuel poverty in UK is monitored using the Low Income High Costs (LIHC) indicator under which a household is fuel poor if its fuel costs are situated above the national median level and if, when he spend that amount, he would be left with a residual income below the official poverty line (DECC, 2014). Therefore, the LIHC indicator represents a relative measure based on the definition of a double threshold comparing households fuel costs and financial resources with the national median bill and income [17].

Recently, inspired by the UK developments the French national observatory of fuel poverty ("*Observatoire National de la Pauvreté Énergétique*"(ONPE)) made use of three different indicators to measure the magnitude of fuel poverty, thus, to make measurable the general definition stated by the Act number 2010-788 of July 12, 2010. One of these three indicators is the 10% threshold of fuel expenditures. The two others are rather based on thermal discomfort feeling and the restriction behavior of households ((ONPE, 2014), (ONPE, 2015)). By the same, Legendre and Ricci (2015) also use three indicators to analyse the fuel poverty magnitude in France and discuss the impact of using different measures on the extend of the phenomenon and the composition of fuel poverty groups. However, a general concertation to state a common definition and to harmonize the use of indicators devoted to tackle the fuel poverty issue is still needed not only in France but also at the EU scale.

Table 1 – Summary of main characteristics of fuel poverty definitions in UK and France

	UK definition	French definition
Main dates	1991: Boardman (1991)'s report 2001: indicator definition	1990: French housing rights Act [a] 2010: Official definition statement [b]
Definition framework	Social and sanitary	Environmental
Definition shape	A precise, measurable, and objective indicator	A general situation characterization with no associated measurable indicator
Definition characteristics	Practical and operational	Non practical and non operational

a. Act number 90-449 of May 31, 1990 named "Loi Besson".
b. Act number 2010-788 of July 12, 2010 dealing with environment national commitment ("Loi Grenelle 2").

2.2   Fuel poverty measures

Measures are classified into three families named objective factual measures, subjective self-reported measures, and composite indices, as summarized in figure 1 and table A.1 from appendix A.1.

2.2.1   Objective factual measures

Objective factual measures of fuel poverty are based on criteria which are measurable and observable. We distinguish expenditures-based measures, restriction behavior approach, and consensual social measures.

Expenditures-based measures

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17. *Cf.* subsection 2.2 or table A below for more details about the LIHC Indicator.

Expenditures-based measures refer to the bulk of measures founded on the contribution of consumption economics. In particular, considering a given household, they take into account the amount of expenditures devoted to satisfy fuel needs with respect to the total available financial endowments. We distinguish the 10% indicator, the After Fuel Cost Poverty (AFCP) indicator, and the Low Income High Cost (LIHC) indicator.

— The 10% indicator

The Fuel Poverty (PF) ratio, representing the 10% indicator, is calculated as following:

$$
\begin{aligned}
\text{FP ratio} \quad &= \quad \frac{\text{Theoretical fuel costs}}{\text{Income}} \\
&= \quad \frac{(\text{Theoretical fuel consumption} \times \text{prices of fuels})}{\text{Income}}
\end{aligned}
\tag{1}
$$

A household is considered to be fuel poor if he needs to spend more than 10% of its income for fuel supply to maintain an appropriate standard of warmth inside its dwelling [18].

The FP ratio considers theoretical rather than actual fuel costs. They represent costs modelled by multiplying fuel requirements (consumption) by fuel prices. These requirements are calculated based on a number of factors including mainly the size of the dwelling, the number of people who live in it, its energy efficiency level, and the mix of used fuels.

Besides, theoretical fuel costs capture four areas of fuel consumption namely the space heating, the water heating, the lights and appliances, and the cooking needs (DECC, 2014). Considering theoretical fuel costs ensures that the household achieves the adequate level of warmth subject to a range of dwelling characteristics and its occupants. Typically, the majority of the fuel bill is accounted for by space heating [19].

Although the FP ratio has the advantage of permitting to take into account the under-consumption phenomenon by comparing theoretical and actual fuel consumption, it is not intended to measure whether households in fact are spending more than 10% of their income on domestic fuel, but rather whether they would need to do so in order to achieve acceptable warmth level in their dwelling on the basis of observed income and modelled physical data related to dwelling space and thermal efficiency (Fahmy et al. (2011), Legendre and Ricci (2015)). Moreover, the FP ratio does not permit to take into account the restriction or privation practices of some households, mainly with regard to heating needs, induced by high fuel costs (Dutreix et al., 2014).

Within the same critical context, Hills (2011) and Moore (2012) argue that the FP ratio does not reliably take into account the income level mainly in the case of households with high income. Indeed, when used to determine the extent of fuel poverty, FP ratio does not include a cut-off for households with high income. Therefore, a significant number of them are found to be fuel poor although in reality the high amount of their fuel spending goes in line with their high income. More fundamentally, although the 10% indicator is still applied in different national contexts, it is definitely not suitable for such an exercice because it was defined by referring to an obsolete and country-specific threshold of energy expenditures. Indeed, the 10% threshold represents the double of median energy expenditure in UK observed during the budget survey of 1988. From this date, this threshold was not updated

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18. *Cf.* footnote number 8 for a standard definition of an appropriate level of warmth.
19. In UK in 2013, on average, around 51% of the theoretical household bill was devoted for space heating costs, 34% for lighting and appliance usage, 12% for water heating, and 3% for cooking costs (DECC, 2014).

even for an application to the UK. Also, before applying it to different national contexts, it should be reviseted to be more suitable with specific national characteristics.

— The After Fuel Cost Poverty (AFCP) indicator

The After Fuel Cost Poverty (AFCP) indicator was developed by Hills (2011). It is based on the comparison between the equivalized income of a given household and the standard threshold of 60% of equivalized national income, where income is considered after subtracting housing costs and domestic fuel costs.

According to this indicator, there is a situation of fuel poverty if:

$$\text{Equivalised (Income } - \text{ Housing costs } - \text{ Domestic fuel costs)} \quad <$$
$$60\% \text{ equivalised (Median income } - \text{ Housing costs } - \text{ Domestic fuel costs)} \quad (2)$$

Despite not based on the constrained income which represents the income after substracting the whole of necessary household expenditures, *i.e.* income after deducing all constrained expenditures like taxes, housing costs, transport expenditures, health and eduction spending, that should be met before turning to fuel expenditures, one advantage of the AFCP indicator is that it takes into account housing costs. They represent only a part of constrained expenditures but when included in calculations they permit to enhance the reliability of results. Another advantage of the AFCP indicator is to permit to identify the aggravating effect of the fuel poverty on monetary (income) poverty. Indeed, its is plausible that people already having important fuel costs be pushed to monetary poverty under the weight of fuel costs. However, when using the AFCP indicator it is expected that an important part of households with very low income will be classified as fuel poor regardless of their fuel requirements. As a consequence, a confusion between fuel and monetary poverties is plausible (Legendre and Ricci, 2015).

— The Low Income High Cost (LIHC) indicator

Defined by Hills (2011, 2012), the Low Income High Cost (LIHC) indicator [20] considers two thresholds to identify fuel poor households. The first deals with the equivalised disposal income that should be less than 60% of the equivalised (national) median disposal income, which is equal to the equivalised income net of housing and domestic fuel cost [21]. The second threshold defines a standard level of fuel expenditures. In particular, the equivalised fuel expenditures should be equal or greater than the required national median fuel expenditures. Therefore, according to this approach, a household is a fuel poor if the following double condition is hold:

$$\begin{cases} \text{Equivalised disposal income } \leqslant \text{ 60\% (Equivalised median disposal income)} \quad (3) \\ \text{Equivalised fuel expenditures } \geqslant \text{ Required national median fuel expenditures} \end{cases}$$

With respect to the AFCP indicator, the advantage of the LIHC indicator is to clearly distinguish between fuel and monetary poverty phenomena by defining two different thresholds. However, as in the case of AFCP indicator, the LIHC is based on the calculation of the income net of only housing and domestic fuel costs, *i.e.* disposal income, not on the

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20. The French nomination of the LIHC is "*Bas Revenus Dépenses Élevées (BRDE)*".
21. Therefore, this first income threshold correspond simply to the definition of the AFCP indicator.

constrained income.

Restriction behavior approach and consensual social measures

The restriction behavior measure stands out from other previous monetary approaches but is still belonging to the group of objectives measures. It is based on the calculation of, both, the actual and the theoretical fuel consumption needed to reach an appropriate dwelling level of warmth [22] and on the determination of the difference between them. When calculated, the theoretical fuel consumption takes into account the energy efficiency of the household dwelling [23].

Beyond permitting the quantifying the restriction behavior of some households, this approach also permits to determine which households have a suitable cost analysis for performing dwelling retrofit energy investments (Charlier (2013, 2014)). The main difficulty that can be encountered when calculating this indicator is still the assessment of theoretical fuel consumption [24].

Belonging to the group of objective factual measures and in addition to expenditures-based ones and to the restriction behavior approach, consensual social measures are also used to assess the magnitude of the fuel poverty. They are found on the contribution of the poverty and deprivation literature which go beyond particular statements of the fuel poverty literature (Townsend (1979), Callan et al. (1993), Gordon et al. (2000)). Indeed, it stipulates that some goods and services are considered as necessary for the human being to be able to conduct a social dignified lifestyle. They are regarded as essential attributes and are socially perceived as life necessities. As a consequence, when considering the energy context, a deprivation state with regard to basic households utilities needs, *i.e.* absence of central heating system in the home, the presence of damp plates in the dwelling,...ect, are considered as an indicator of a fuel poverty when using the consensual social approach.

In summary, the use of consensual social measures aims to capture the wider elements of fuel poverty namely energy poverty by focusing on social exclusion and material deprivation notions, as opposed to approaches based solely on expenditures-based indicators. The use of consensual social measures relies on the use of several objective indicators like for example:

— the presence of damp walls and/or floors,
— the lack of central heating,
— the presence of rotten window frames,
— the access to an electricity system,
— the household appliance ownership.

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22. *Cf.* footnote number [8] for a standard definition of an appropriate level of warmth.

23. In France, information on the dwelling energy efficiency are available due to the publications in 2014 of the results of the PHÉBUS survey, conducted from April to October 2013, dealing with housing performance, equipment, needs and uses of energy ("*Performance de l'Habitat, Équipements, Besoins et Usages de l'énergie*" (PHÉBUS)) conducted by the ministry of ecology, sustainable development and energy ("*Ministère de l'Écologie, du Développement durable et de l'Énergie*" (MEDDE)), the general commission for sustainable development ("*Commissariat Général au Développement Durable*" (CGDD)), and the service of observation and statistics ("*Service de l'observation et des statistiques*" (SOeS)). PHÉBUS survey is divided into two parts: 1/-a face-to-face interview with the occupants of the home about their energy consumption, expenditures, and attitudes and 2/-an energy performance diagnosis of the dwelling. It allows to study fuel poverty since it contains information on disposable income information as well as energy expenditures and attitudes toward energy consumption (ONPE, 2014). Also, *Cf.* appendix F.

24. Charlier (2013, 2014) has assessed theoretical fuel consumption using Promodul software by taking into account dwelling characteristics and by referring to the 3CL-DPE method presented in the French Act of September 2006 dealing with energy performance diagnosis for existing buildings offered for sale in France (JORF, 2006).

2.2.2 Subjective self-reported measures

Subjective fuel poverty measures are based on personal opinions, interpretations, points of view, and judgment. They are usually constructed by referring to households self-reported answers on questions asked by social investigators during survey. The fuel poverty literature shows that several questions can conduct to the definition of subjective measures. The most frequently used ones are:

— Do you suffer from thermal discomfort?
— Do you experience difficulty to pay utility bills (over the past period)?
— Do you feel to be able to afford energy?
— Are you satisfied with heating facilities?

Several studies use subjective measures to study the fuel poverty. For example, Healy (2003) considers three subjective indicators based on questions cited above to analyse the fuel poverty in Ireland and the UE. Also, INSEE ENL (2006) and EPEE (2006) analysis of fuel poverty is based subjective indicators. In particular, in EPEE (2006) the fuel poverty is defined as "*the household's difficulty, sometimes even the inability, to adequately heat its dwelling at a fair price*", and in the French dwelling survey namely INSEE ENL (2006) households are invited to answer the question "*During the last winter, inside your home, do you suffer from cold during at lest 24 hours?*". Within the same framework, Price et al. (2012) exploring the links between objective and subjective measures of fuel poverty in UK use one subjective self-declared measure of fuel poverty based on whether consumers feel able to afford their energy.

Since these subjective indicators are constructed on the basis of self-reported answers, results of different studies should be interpreted with caution mainly with respect to the identification of fuel poor households. Because of the same reason, the interpretation of results may also sometimes reveal opposition compared to those determined on the basis of objective factual measures although the reintroduction of a self-reported measures, in addition to expenditures (objective) based measures [25], would give a valuable aid to policy development (Price et al., 2012).

2.2.3 Composite indices

Composite indices were created as a compromise between the simplicity of uni-dimensional indicators and the need to account for the multidimensional nature of fuel poverty. They represent an attempt to overcome the shortcomings of one-dimensional indicators while at the same time producing an outcome that condenses the information to single and easy to interpret metrics (Nussbaumer et al. (2011), Thomson and Snell (2013)). Indeed, based on a set of sub-indicators they aim to capture the multidimensional aspects of fuel poverty that cannot be depicted in a single indicator. Nevertheless, the main drawback of composite indices is that, by combining variables, some form of information reduction or loss can be induced, with all the associated methodological issues and required assumptions and simplifications it implies (including value judgments). Therefore, if not meticulously handled composite indices can be misleading in terms of policy recommendations.

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25. Fuel poverty in UK is currently monitored using the LIHC indicator (DECC, 2014) (*Cf.* subsection 2.2.1 above or the table A for a presentation of this indicator).
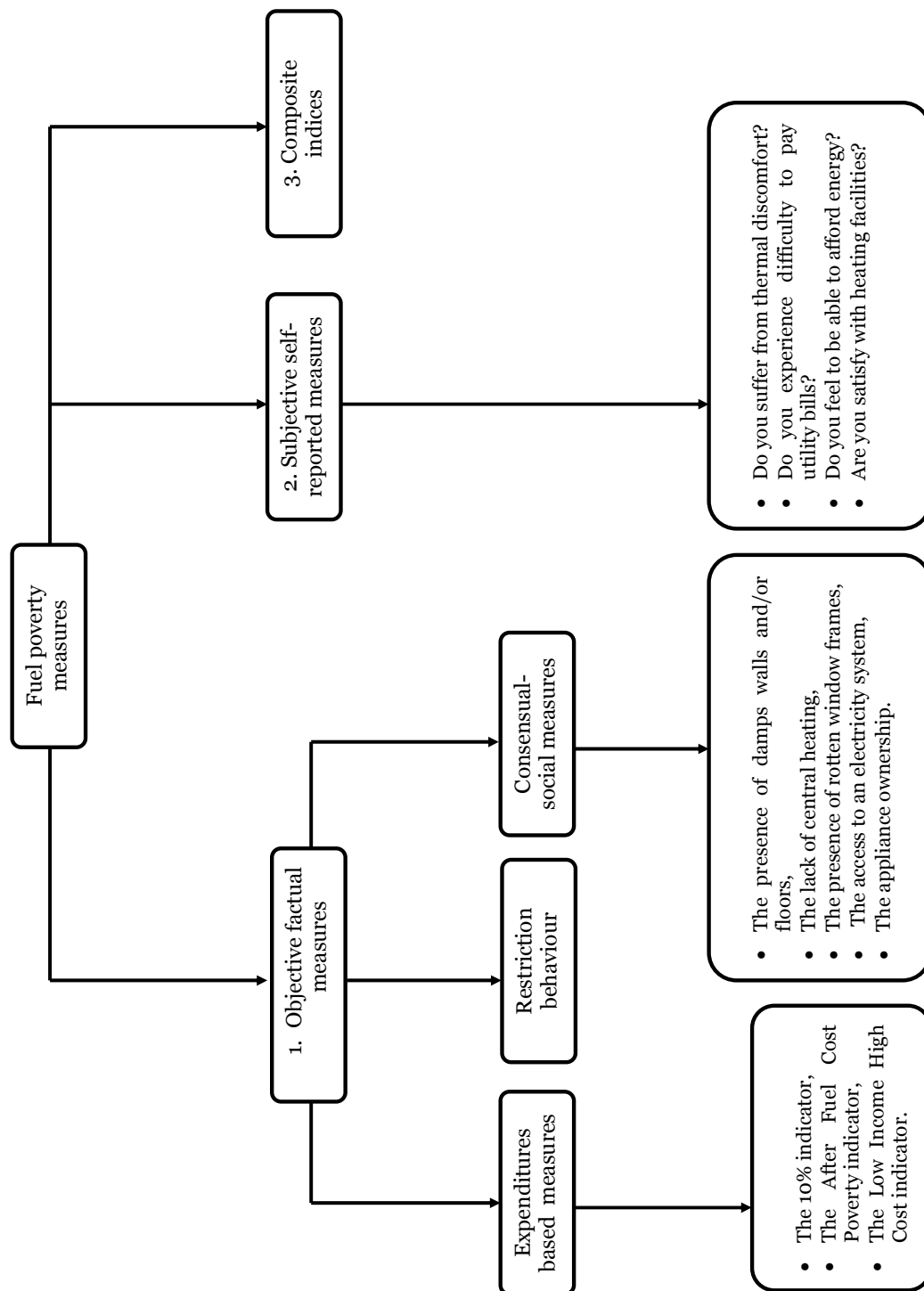
Figure 1. Summary of fuel poverty measures. Source: authors elaboration.

3 Profile of fuel poor households: qualitative analysis

This section aims to sit-down the analysis of the sensitivity of fuel poor households to energy prices fluctuations, conducted in section 4. It proposes to characterize fuel poor households and to show the variability of fuel poverty situations. It is divided into two subsections. In subsection 3.1, we start by determining which households are fuel poor by using objective fuel poverty measures. Then, in subsection 3.2, we study the profile of fuel poor households and identify their common characteristics. To that end we use a qualitative approach based on three complementary methods namely Multiple Correspondence Analysis (MCA), Hierarchical Clustering Analysis (HCA), and Partition- ing Clustering Analysis (PCA). We use data extracted from the EU-SILC database covering the time period going from 2008 to 2013.

3.1 Groups identification (or calculation of fuel poverty rates)

To determine groups of fuel poor households, we use three objective factual measures which are the 10% indicator, the LIHC m^2 indicator, and the LIHC cu indicator [26]. Our sample is composed of 9978 households. We determined groups of fuel poor households each year of the time period going from 2008 to 2013. Calculations are detailed in appendix B.

Results are summarized in table 2 and figure 2. They show that when using the 10% indicator,
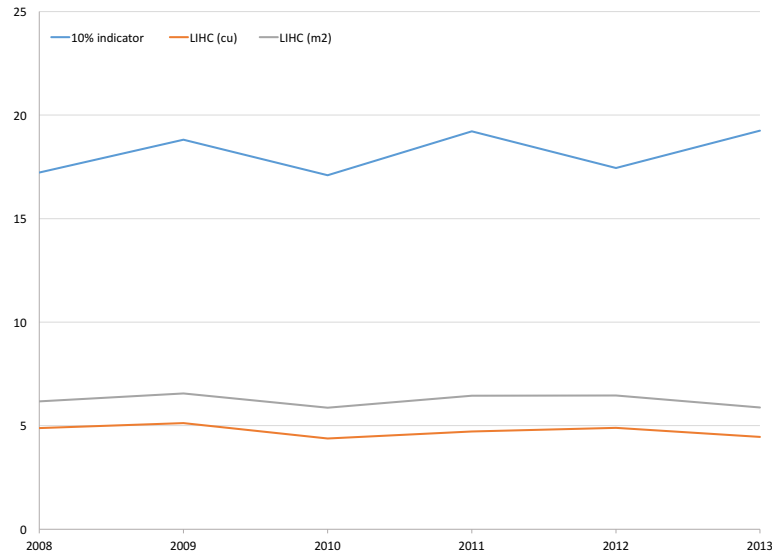

Figure 2. Evolution of fuel poverty rates between 2008 and 2013 according to the 10% and LIHC indicators

the fuel poverty rate varies between 17.10% and 19.25% and is rather high compared to ONPE (2014, 2015) estimations where fuel poverty rates varies from 10.4% to 14.4%. The use of different base years of calculation in each study can explain such difference. In particular, the fuel poverty rate in ONPE (2014, 2015) for the year 2014 was calculated by using 2006 housing survey data whereas our annual rates are calculated using annual data for the time period going from 2008 to 2013. Moreover, we expect that the quality of data and some data adjustments may also explain differences between results. When we use the LIHC approach, fuel poverty rates are lower that rates calculated for France which turn around 11% ONPE (2014, 2015). In particular when using the LIHC cu criterion, fuel poverty rate varies from 4.38% to 5.13%, whereas it varies from 5.87%

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26. Because of the bad quality of data describing the housing cost (code variable in the EU-SILC database is is HH060), we were not able to determine groups of fuel poor households according to the AFCP indicator. This may not put into question the rest of the study.

and 6.56% when considering LIHC m^2 for the time period going from 2008 to 2013. As for the 10% indicator, we expect that differences in data base are the main determinant of such disparity.

By comparing fuel poverty rates obtained from 10% indicator with those obtained from LIHC indicator, we remark that, as usually stated by the literature, the 10% indicator over-estimate the number of fuel poor households.

By extension of these preliminary results, we determined the number of fuel poor households during more than one year. Indeed, we aim to analyze the inertia of fuel poverty situation. Is it a time lasting or rather a short-run situation? In other words, is there any premises of adjustment behavior supporting that fuel poor households behave in a way to quickly overcome fuel poverty?

Results are presented in tables 3a and 3b. They highlight that fuel poverty corresponds to a short-term state. It lasts at most three years according to our calculations. In particular, table 3a shows that no more than 38 households from 541 ones which are fuel poor according to the LIHC m^2 indicator are still poor for two successive years, *i.e.* 2012 and 2013, and only 1 is still suffering from fuel poverty during three successive years, *i.e.* from 2011 to 2013. These results support the idea according to which fuel poor households follow different strategies when it comes to inventing solutions to escape fuel poverty and to find ways of satisfying at least a part of their basic energy needs (Brunner et al., 2012).

Table 2 – Number of fuel poor households and evolution of fuel poverty rate according to the 10% and LIHC indicators

Indicator	2008		2009		2010		2011		2012		2013	
	Numb [27]	Rate	Numb.	Rate	Numb	Rate	Numb	Rate	Numb	Rate	Numb	Rate
10%	494	17.23%	539	18.81%	492	17.10%	554	19.22%	503	17.45%	559	19.25%
LIHC (cu)	467	4.88%	490	5.13%	421	4.38%	454	4.72%	471	4.90%	432	4.46%
LIHC (m^2)	568	6.18%	600	6.56%	538	5.87%	592	6.45%	596	6.46%	541	5.88%

Table 3a – Number of fuel poor households during more than one year according to the 10% and LIHC indicators

Indicator	[2008-2013]	[2009-2013]	[2010-2013]	[2011-2013]	[2012-2013]
10%	0	0	0	1	29
LIHC (cu)	0	0	0	1	28
LIHC (m^2)	0	0	0	1	38

Table 3b – Number of fuel poor households during more than one year according to the 10% and LIHC indicators

Indicator	[2008-2009]	[2008-2010]	[2008-2011]	[2008-2012]	[2008-2013]
10%	33	2	0	0	0
LIHC (cu)	29	1	0	0	0
LIHC (m^2)	41	1	0	0	0

3.2   Characteristics of fuel poor households

In order to determine the characteristics of fuel poor households and draw their profile, we use three standard and complementary methods namely the Multiple Correspondence Analysis (MCA) which permits to summarize the information contained in a multivariate data set and particularly to group together individuals and variables having the same profiles [28], the Hierarchical Clustering

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27. It represents the number of fuel poor households in our sample according to the given criterion. We give it because we will refer to it in the next paragraph.

28. Generally speaking, Multiple Correspondence Analysis (MCA) belongs to the family of principal component methods. They include:

Analysis (HCA) used to identify groups of similar observations, and Partitioning Clustering Analysis (PCA) which permit to split a database into several groups having the same profiles.

To run the MCA on the 2013 three groups of fuel poor households [29], we start by considering insights of the literature with respect to the drivers of fuel poverty [30] based on which we select from the EU-SILC database 18 variables defined as determinants of fuel poverty. Table 4 presents the list of these variables describing characteristics of, both, households and their dwelling. Appendix D gives a technical description of preliminary steps followed to manage the dataset before running the MCA, which accepts, in essence, only qualitative variables.

Table 4 – List of variables and their status in the MCA

Variable status in the MCA	Variable name and codes in the EU-SILC database
Qualitative active (1)	Variable describing household situation
	Type of the household (HX060) [31]
	Sex of the household reference person (SEXEPR)
	Age of the household reference person (AGEPR)
	Socioprofessionnal category of the household (CSMEN)
	Ownership of cars (HS110)
	Monthly total financial endowments (TOTREVEN)
	Monthly total housing costs [32] (HH070)
	Poverty indicator at the threshold of 60% (HX080)
Qualitative active (2)	Variable describing dwelling characteristics
	Type of housing (TYPLOG)
	Type of housing tenure (HH021/HH020)
	Ownership of central or electric heating system (CHAUF)
	Indoor difficult to heat (DIFCHAUF)
	Roof leaks, walls / floors / foundations damp, rot in window frames or floor (HH040)
	Area in m^2 of the dwelling (SURFACE)
	Dwelling acquisition date (DATACH)
	ZEAT residence [33] (ZEAT)
Quantitative supplementary	Other variable describing household characteristics
	Number of the employed persons in the household (NACTOCCUP)
	Number of children (NENFANTS)

Figure 3 summarizes results of the MCA. In particular, graphics of figure 3 display clouds of individuals and associated variables categories/levels whereas figures E.1, E.2, and E.3 display dispersion of groups according to each variable included in the MCA.

Regarding the quality of graphical representations, results show the first two dimensions/axes explain between 12.73% and 13.2% of the total inertia/variability contained in the dataset, depending on which indicator has been used to determine the group of fuel poor households, *i.e.* 10% or LIHC, which is rather acceptable [34]. They also show that results of the MCA are quite

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— Principal Component Analysis (PCA) which is suitable for analyzing database containing quantitative/continuous variables,
— Correspondence Analysis (CA) which is used to handle a data set formed by two qualitative/categorical variables,
— Multiple Correspondence Analysis (MCA) which represents an extension of simple CA used to analyze a database containing more than two categorical variables.

29. We have one group by indicator of fuel poverty. According to the results of the table 2, based on 10% indicator, LIHC (*cu*) indicator, and LIHC (m^2) indicator, we respectively count 559, 432, and 551 fuel poor households. Otherwise, we note that we have run MCA for each year of the time period going from 2008 to 2013. Results are quite similar to those of 2013 and are available upon request.

30. *Cf.* appendix C.

31. Code into brackets associated to each variable in this table refers to the code of the variable in the EU-SILC initial database).

32. Housing costs include renting, electricity, heating, water, and gas expenditures.

33. ZEAT, which means in French "*Zone d'études et d'aménagement du territoire*", represents a regional French subdivision which corresponds to the first category of the nomenclature of regional unities statistics (NUTS 1) of the EU.

34. Although such value can seem small, such case is frequently encountered. Indeed, the number of dimensions in an MCA is equal to the number of levels of variables minus 1. More important the number of levels is, smaller

similar irrespective to fuel poverty indicator used to calculate groups of fuel poor households. In particular, graphics of figure 3 show an opposition between households with regard to the first axis according to the type of the household (HX060), the age (AGEPR), the dwelling acquisition date (DATACH), the housing costs (HH070), and the dwelling surface (SURFACE). More precisely, in contrast to the right hand side group of households which is an intermediate age group, having children, and living in large and costly [35] dwelling, the left hand side group represents rather elderly households, *i.e.* [61-80years), with no children, living in small or moderate surface dwelling, *i.e.* [25-40m2) or [40-70m2), purchased before the first thermal regulation of 1975. The same graphics also show an opposition between households according to the second axis based on the type of housing (TYPLOG), the dwelling quality (HH040), and the ownership of cars (HS110). Households living in an apartment situated in a large building, *i.e.* 3-9 apart. building or >10 apart. building, and having no financial endowments to own a car are opposed to households living in a detached house or in an apartment in small building and suffering from roof leaks or floors damp. These oppositions are corroborated by results of figures E.1, E.2, and E.3 from appendix E, in particular, for the variables housing costs (HH070) and ownership of cars (HS110) [36].

As expected, results of MCA have permitted to map groups of fuel poor households having the same characteristics. Nevertheless, at this stage of the analysis, opposition between these groups are more explicit when considering households characteristics, *i.e.* Type of the household (HX060), Age (AGEPR), Monthly total financial endowments (TOTREVEN), rather than when considering (some) dwelling characteristics, *i.e.* Indoor difficult to heat (DIFCHAUF), Ownership of central or electric heating system (CHAUF), Roof leaks (HH040).

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the part of the variability explained by the two first dimensions will be because each dimension will explain a just small part of the total variability contained in the dataset (Husson et al., 2016). In our sample, we have counted 49 levels for 16 active variables (*Cf.* section D.2.2 of the appendix D). Such important number of levels explains the small part of variability explained by the first two dimensions of the MCA (histograms of eigenvalues are available of request).

35. Costly refers here to the total housing costs (HH070).

36. It is worthy to note that interpretation of the results of the MCA based on LIHC (*cu*) indicator, *i.e.* graphics 3(c) and 3(d), call for some caution. Indeed, we suspect the presence of a "Horseshoe phenomenon" also called "Guttman effect" (Guttman (1955), Flament and Milland (2003), Diaconis et al. (2008), Husson et al. (2016)). It occurs when the two principal dimensions of the MCA are related by a purely convex or concave function despite the original relationship being more linear. It implies an individuals cloud extremely structured according to the first axis where this first axis opposes the extreme profiles while the second axis opposes the intermediate to extreme. Two important causes of this phenomenon are the presence of variables coded as classes or the redundancy between (active) variables. Despite the fact that the presence of such phenomenon does not in any case put into question the results of the MCA, we have performed two cases of sensitivity analysis. In the first case, we have incorporated the variable "Age (AGEPR)" as a supplementary variable rather than as active and we have omitted the variable "Total financial endowments (TOTREVEN)" initially coded in classes. Indeed, basically introduced as proxy of income, we consider that the latter variable contains information that can be reflected by the variable "Poverty indicator (HX080)" already incorporated in the MCA. In other words, the rational behind omitting "Total financial endowments (TOTREVEN)" variable is to prevent plausible information redundancy. In the second case, we have outright omitted the two variables "Age (AGEPR)" and "Total financial endowments (TOTREVEN)". After running the two new MCA, results was not significantly different.
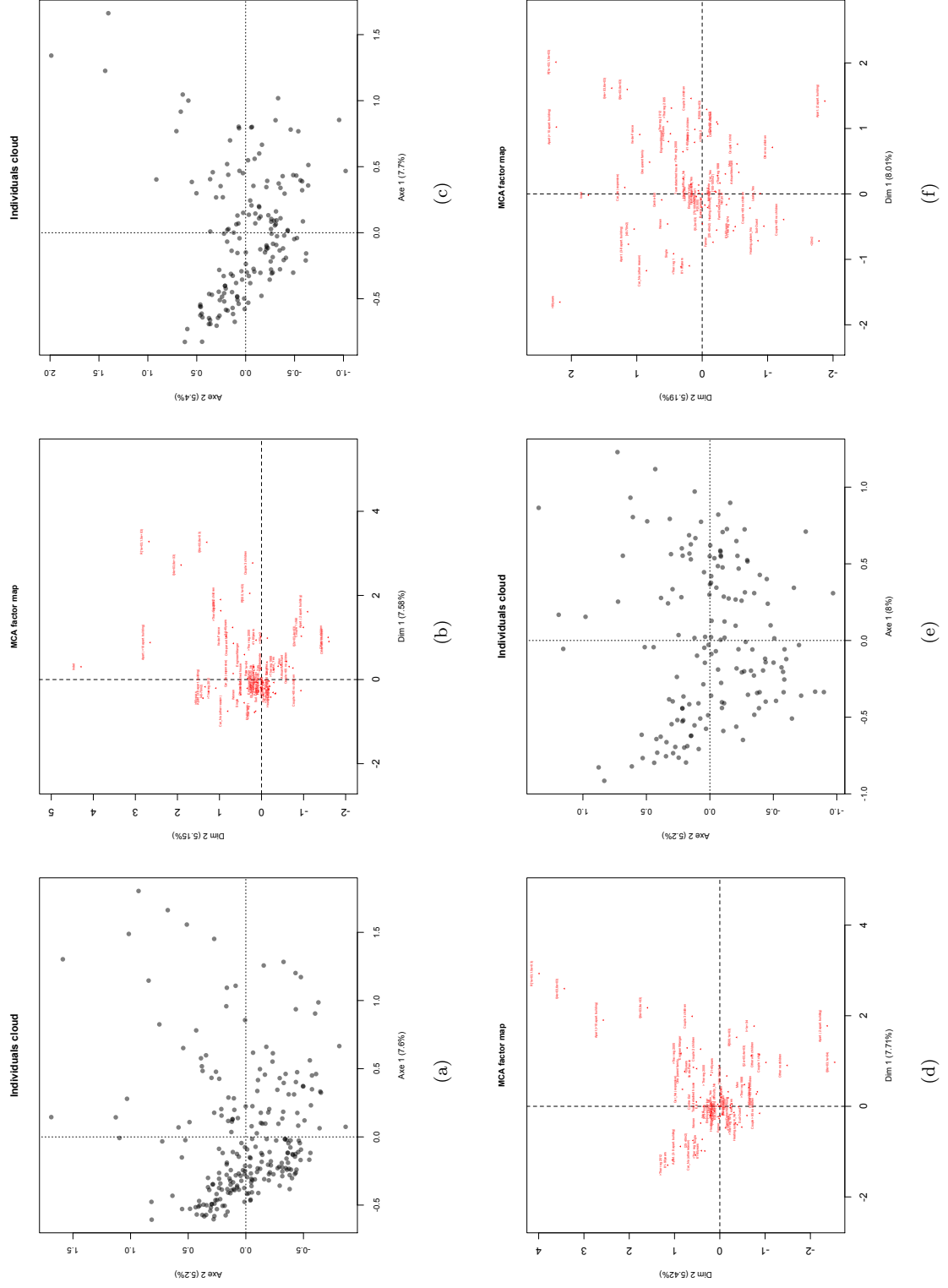
Figure 3. (a) Cloud of households - 10% indicator; (b) Levels dispersion - 10% indicator; (c) Cloud of households - LIHC (cu) indicator, (d) Levels dispersion - LIHC (cu) indicator, (e) Cloud of households - LIHC (m^2) indicator, (f) Levels dispersion - LIHC (m^2) indicator

In order to determine more in details common characteristics of groups of fuel poor households, we run a Hierarchical Clustering and Partitioning Analysis (HCPA), based on MCA analysis. It permits to clearly identify groups of similar observations by splitting the set of MCA input data into several groups having the same profile. Since we are working on a sample of fuel poor households, HCPA will permit to split it into sub-groups having the same characteristics.

Results of HCPA are displayed in figure 4. They show that fuel poor households are partitioned into 7, 6 and 4 clusters depending on the indicator used to determine the group of fuel poor households. Households belonging to the same cluster are homogenous but when going from one cluster to another they become different[37]. The important number of clusters inside the same group of fuel poor households highlights the variability of fuel poverty situations.

If we consider the 10% indicator[38], results show that inside the cluster 1, which contains the most important part of poor households, *i.e.* 29.75%, most fuel poor households are single (98.61% / 50.82%)[39], old (55.55% / 28.09%)[40] women (94.44% / 54.54%), monthly earning less than 2000€ (97.22% / 83.05%), living rather in an energy inefficient dwelling (58.33% / 30.57%) suffering from leaks problem (4.16% / 16.94%), and having a car (33.33% / 73.14%). Conversely, they do not have necessary indoor heating problem which interestingly supports that fuel poverty is rather a monetary problem. In other words, a fuel poor household can correctly heats its dwelling but the weight of heating expenditures in its total budget can push him toward a poverty situation that can be exacerbated by heating difficulties induced by a low level of dwelling energy efficiency. In this framework, cluster 2, which contains 18.18% of total fuel poor households, shows that 25% / 50.41% of fuel poor households are poor men (84.09% / 45.45%) worker or employee (34.09% / 63.63%) living in a detached (84.09% / 69%) and (rather) energy inefficient dwelling[41] (63.63% / 30.57%), and having a car (97.72% / 73.13%). Inspite of some common characteristics between profiles of fuel poor households belonging to clusters 1 and 2, we can draw from looking at the composition of clusters 4 to 7, which contain together 52.05% of fuel poor households, a different profiles. For example, in cluster 7, fuel poor households are usually couple (37.5% / 3.71%) belonging to an intermediate age class[42] (87.5% / 29.75%) with at least two children (37.5% / 3.71%), living in a large dwelling (50% / 18.18%), and belonging to a high socio-professional category, *i.e.* engineer or manger, (50% / 9.09%).

Without going in a confusing detailed lecture of numerical results, HCPA based on the LIHC (*cu*) and LIHC (m^2) criteria go in the same direction of those based on the 10% indicator. As a consequence, at this stage, the main conclusion that we can support is that when considering a group of fuel poor households determined based on conventional measures of fuel poverty, it is still difficult to identify a "*profile-type*" of the fuel poor household although the fact that we can identify some common characteristics. Even if we manage to determine it, this implies to exclude an important number of fuel poor households from being considered. In our example, this is the case of households belonging to clusters containing less than 15% of fuel poor households[43]. Within this framework, tables 5, 6, and 7 based on results of the HCPA, give an illustrative description of the profile of the most representative fuel poor household inside each cluster with respect to

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37. Formally speaking, this means that the intra-cluster variability is low (homogenous households) and inter cluster-variability is high (heterogeneous households) (Husson et al., 2016).

38. In this paragraph, we focus on presenting numerical results for only the most representative cluster, *i.e.* cluster 1 in the case of 10% indicator, cluster 3 in the case of LIHC (*cu*) indicator, and cluster 1 and 2 for the case of LIHC (m^2) indicator. Nevertheless, tables presenting all numerical results are available on request.

39. It means that 98.61% of households belonging to the cluster are single given that 50.82% of households in the global sample - all clusters considered- of fuel poor households are single.

40. Dominant age class for this cluster is [81-90years].

41. Dwelling purchased before 1974, the date of the first thermal regulation.

42. Dominant age class for this cluster is [41-60years].

43. *Cf.* last lines of tables 5, 6, and 7.

the indicator used to calculate the group of fuel poor households[44]. Each representative fuel poor household, thus, each cluster, represents, a distinct case of fuel poverty that calls for specific remedies.

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44. The expression "the most representative fuel poor household" has a formal meaning here: we consider the closest household to the center of the cluster, thus, the household who has the smallest distance to the cluster center.
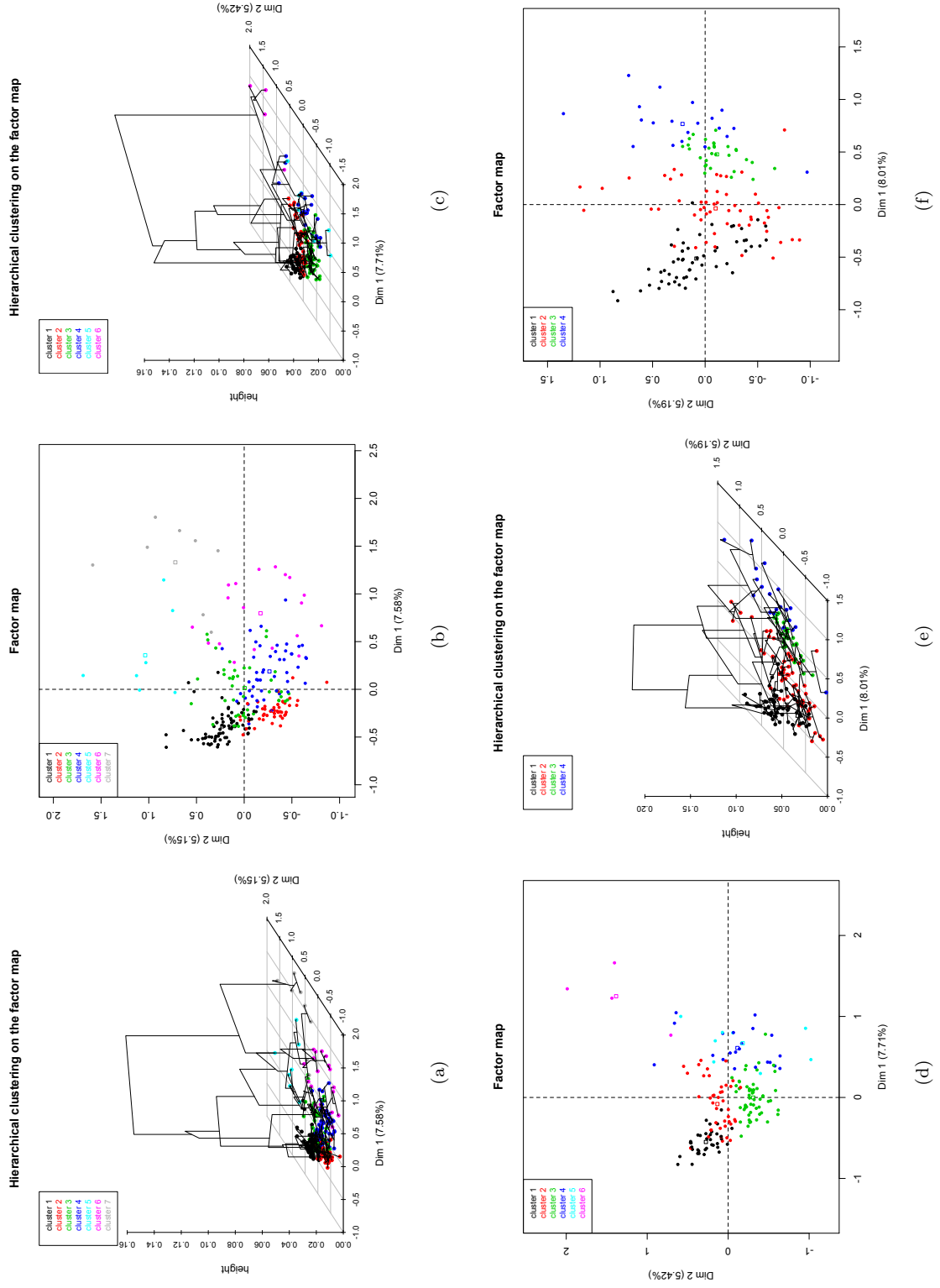
Figure 4. (a) Clusters in 3D - 10% indicator, (b) Clusters in 2D - 10% indicator, (c) Clusters in 3D - LIHC (cu) indicator, (d) Clusters in 3D - LIHC (cu) indicator, (e) Clusters in 3D - LIHC (m^2) indicator, (f) Clusters in 2D - LIHC (m^2) indicator

Table 5 – Description of profiles of the most representative fuel poor households according to the 10% indicator

	Representative profile description and weight of the cluster in the total sample						
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
Variables describing household situation							
Type of the household (HX060)	Single	Couple	One-parent family	Couple	Single	Couple	Couple
Sex of the household reference person (SEXEPR)	Women	Men	Women	Men	Women	Women	Men
Age of the household reference person (AGEPR)	74	87	52	58	90	38	44
Socio-professional category of the household (CSMEN)	Worker[45]	Artisan	Employee[46]	Worker[47]	Worker[48]	Worker[49]	Employee[50]
Ownership of cars (HS110)	No[51]	Yes	Yes	Yes	No[51]	Yes	Yes
Monthly total financial endowments (TOTREVEN)	800€	1020€	838€	1400€	1500€	2000€	4500€
Monthly total housing costs (HH070)	125€	270.08€	153.25€	387.25€	870.41€	338.91€	1260.08€
Poverty indicator at the threshold of 60% (HX080)	Poor	Poor	Poor	Not poor	Not poor	Poor	Not poor
Variables describing dwelling characteristics							
Type of housing (TYPLOG)	Detached house	Detached house	Detached house	Detached house	Apartment[52]	Detached house	Detached house
Type of housing tenure (HH021/HH020)	Owner	Owner	Owner	Owner	Owner	Owner	Owner
Ownership of central or electric heating system (CHAUF)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Indoor difficult to heat (DIFCHAUF)	No	Yes	Yes	No	Yes	No	Yes
Roof leaks, walls / floors damp, rot in window (HH040)	No	No	No	No	No	No	No
Area in m^2 of the dwelling (SURFACE)	130m2	80m2	99m2	110m2	60m2	125m2	280m2
Dwelling acquisition date (DATACH)	1962	1950	1981	1992	1994	2000	2011
ZEAT residence (ZEAT)	East	South-West	East	Central-East	South-West	East	West
Other variables describing household characteristics							
Number of the employed persons (NACTOCCUP)	0	0	1	1	0	2	2
Number of children (NENFANTS)	0	0	1	0	0	0	4
Weight of the cluster in the sample	29.75%	18.18%	18.18%	19.83%	2.89%	7.85%	3.30%

45. "*Ouvrier qualifié de la manutention, du magasinage et du transport*".
46. "*Personnel des services directs aux particuliers*.".
47. "*Ouvrier qualifié de type artisanal*".
48. "*Ouvrier qualifié de type industriel*".
49. "*Ouvrier non qualifié de type industriel*".
50. "*Profession intermédiaire administrative et commerciale des entreprises*".
51. For a reason other than financial.
52. >10 apart. building.

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Table 6 – Description of profiles of the most representative fuel poor households according to the LIHC (*cu*) indicator

	Representative profile description and weight of the cluster in the total sample					
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Variables describing household situation						
Type of the household (HX060)	Single	Single	Couple	Couple	Couple	Couple
Sex of the household reference person (SEXEPR)	Women	Women	Men	Men	Women	Men
Age of the household reference person (AGEPR)	84	58	65	40	58	41
Socio-professionnal category of the household (CSMEN)	Employee[53]	Employee[54]	Worker[55]	Engineer[56]	Artisan	Worker[57]
Ownership of cars (HS110)	Yes	Yes	Yes	Yes	Yes	Yes
Monthly total financial endowments (TOTREVEN)	669€	1000€	1460€	2000€	1700€	4000€
Monthly total housing costs (HH070)	248.5€	242.16€	196.66€	294.75€	553.5€	1380.75€
Poverty indicator at the threshold of 60% (HX080)	Poor	Poor	Poor	Not poor	Poor	Poor
Variables describing dwelling characteristics						
Type of housing (TYPLOG)	Town-detached house	Town-detached house	Town-detached house	Detached house	Town-detached house	Detached-house
Type of housing tenure (HH021/HH020)	Owner	Owner	Owner	Owner	Owner	Owner
Ownership of central or electric heating system (CHAUF)	Yes	Yes	Yes	Yes	Yes	Yes
Indoor difficult to heat (DIFCHAUF)	Yes	Yes	Yes	No	Yes	Yes
Roof leaks, walls / floors damp, rot in window (HH040)	No	No	No	No	No	No
Area in m^2 of the dwelling (SURFACE)	80m2	100m2	155m2	110m2	140m2	90m2
Dwelling acquisition date (DATACH)	1973	1979	1988	1997	2006	2006
ZEAT residence (ZEAT)	West	North	Bassin Parisien	Middle-East	North	East
Other variables describing household characteristics						
Number of the employed persons in the household (NACTOC-CUP)	0	0	0	2	1	2
Number of children (NENFANTS)	0	0	0	2	3	2
Weight of the cluster in the sample	21.81%	24.84%	33.33%	12.72%	4.84%	2.42%

53. "*Personnels des services directs aux particuliers*".
54. "*Employés civils et agents de service de la fonction publique*".
55. "*Ouvrier qualifié de type industriel*".
56. "*Profession de l'information, des arts et des spectacles*".
57. "*Technicien*".

Table 7 – Description of the profiles of the most representative fuel poor households according to the LIHC (m^2) indicator

	Representative profile description and weight of the cluster in the total sample			
	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Variables describing household situation				
Type of the household (HX060)	Single	Couple	Couple	Other
Sex of the household reference person (SEXEPR)	Women	Women	Men	Women
Age of the household reference person (AGEPR)	89	56	53	38
Socio-professionnal category of the household (CSMEN)	Worker [58]	Employee [59]	Worker [60]	Employee [61]
Ownership of cars (HS110)	Yes	Yes	Yes	Yes
Monthly total financial endowments (TOTREVEN)	527€	1500€	2000€	3000€
Monthly total housing costs (HH070)	156.91€	271.83€	289.58€	539.5€
Poverty indicator at the threshold of 60% (HX080)	Poor	Poor	Poor	Poor
Variables describing dwelling characteristics				
Type of housing (TYPLOG)	Detached house	Detached house	Detached house	Detached house
Type of housing tenure (HH021/HH020)	Owner	Owner	Owner	Owner
Ownership of central or electric heating system (CHAUF)	Yes	Yes	Yes	Yes
Indoor difficult to heat (DIFCHAUF)	Yes	No	No	Yes
Roof leaks, walls / floors damp, rot in window (HH040)	No	No	No	No
Area in m^2 of the dwelling (SURFACE)	100m2	80m2	100m2	160m2
Dwelling acquisition date (DATACH)	1972	1983	2000	2009
ZEAT residence (ZEAT)	Mediterranean	South-West	East	East
Other variables describing household characteristics				
Number of the employed persons in the household (NACTOCCUP)	0	0	1	1
Number of children (NENFANTS)	0	1	2	4
Weight of the cluster in the sample	34.17%	34.17%	18.98%	12.65%

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58. "*Ouvrier non qualifié de type industriel.*"
59. "*Personnel des services directs aux particuliers.*"
60. "*Ouvrier qualifié de type artisanal.*"
61. "*Employée de commerce.*"

4 Are fuel poor households more sensitive to energy price variations?

In this section, considering a sample of 827 households observed for the time period going from 2008 to 2014 [62], we aim to analyze the sensitivity of households, in particular fuel poor households, to energy price fluctuations by estimating their own price elasticity of heating energy demand: are fuel poor households more sensitive to energy price variations?

We use a Panel Threshold Regression (PTR) model whose main advantage is to permit to take into account plausible non linearities, *i.e.* different values of elasticities, inherent to the impact of the income level on the household decision of heating energy consumption. Indeed, we expect that affluent households will not react in the same way as a poor ones after an increase of energy prices [63]. Probably, poor households will restrain more their energy expenditures than affluent. We can, as a consequence, identify groups of households reacting differently to price variations according to their financial endowment. Each group belongs to a different regime and is characterized by its different own price elasticity of energy expenditures, where each regime is defined according to the value of the defined threshold variable. From practical point of view, these properties clearly reflect threshold effects and call for the use of a PTR model to take into account these plausible non linearities. In our case, the threshold regression describes the jumping character in the relationship between energy prices and heating energy expenditures and "*specifies that individual observations can be divided into classes based on the value of an observed variable*" (Hansen, 1999). This observed variable is called the threshold variable, and is the income.

As a consequence, by using a PTR model, we endogenously distinguish between groups of households reacting differently to prices variations according to their income level. By looking at the households composition of each groups, our goal is to see if there is a clear-cut difference in the reaction, *i.e.* elasticity, of fuel poor households compared to the reaction of non fuel poor: is the elasticity of fuel poor households to price variations more or less important than the elasticity of non poor households? This means that we (voluntarily) choose to not exogenously divide the whole sample of households into two groups where the first represents fuel poor households and the second the non fuel poor to compare, after that, elasticities of two groups [64]. We choose rather to perform the PTR regression on the whole sample of households and to discriminate after that between fuel poor and non-fuel poor households by considering the estimated value of the threshold variable, *i.e.* the income. Indeed, by knowing the value of the threshold variable, we can determine if households belonging to each regime are mostly fuel poor or not.

We start in subsections 4.1 by giving some methodological aspects on the Panel Threshold Regression (PTR). Then, we present in subsection 4.2 specifications, variables, and data sources. Finally, we discuss findings in subsection 4.3.

4.1 Methodological aspects on the PTR model

Hansen (1999) proposed the Panel Threshold Regression (PTR) for estimating and testing threshold effects in non-dynamic panels. After identifying the threshold variable, the model allows for dividing observations into different groups according to the estimated value of the threshold

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62. *Cf.* subsection 4.2 below for a detailed presentation of data and sources.

63. To define poor households, we consider here the official poverty threshold, *i.e.* 60% of the median national income (INSEE, 2014).

64. Even if this is theoretically possible, we are not able to do it on a panel sample in our case. We can do it only within the framework of cross-section analysis. In fact, according to insights of the section 3, the sample composed of fuel poor households is too small to permit to perform estimations for the time period for which data are available, *i.e.* 2008-2013. *Cf.* tables 3a and 3a.

variable where the time series and cross-sections are used in order to identify the regimes. Based on this procedure, it is then possible to test and estimate the threshold effects without assuming the homogeneity the estimated function. Each group will have its own estimated coefficients and each group defines one regime of the model. The PTR model assumes a transition from one regime to another based on the value of a threshold variable. In a model with two regimes, if the threshold variable is below a certain value, estimated function will be defined by one model, whereas it is defined by another model if the threshold variable exceeds the threshold parameter. At each date in the threshold model, observations are divided into a heterogeneous small number of groups having the same estimated coefficients. The heterogeneity of groups is then endogenously determined by the threshold model and not specified ex ante by splitting the whole sample into n groups.

If we consider two regimes, the PTR model is written as follows:

$$y_{it} = \mu_i + \beta_1 x_{it} I\left(q_{it} \leqslant \gamma\right) + \beta_2 x_{it} I\left(q_{it} > \gamma\right) + \xi_{it} \tag{4}$$

for $i = 1, ..., N$ and $t = 1, ..., T$, where N and T denote the cross-sections and time dimensions of the panel, respectively. y_{it} represents the dependent variable and is a scalar, x_{it} is a k-dimensional vector of time-varying exogenous variables, μ_i represents the fixed individual effect, $I\left(.\right)$ is the indicator function, and u_{it} are the errors. We note that the estimation of a threshold model requires the use of a balanced panel.

The observations are divided into two regimes depending on whether the threshold variable q_{it} is smaller or larger than the threshold γ. No constraint is imposed on the choice of the threshold variable except for the fact that it cannot be the contemporaneous endogenous variable and cannot be time-independent. The regimes are distinguished by different regression slopes β_1 and β_2. For the identification of β_1 and β_2, it is required that the element of x_{it} be time invariant. The error x_{it} is assumed to be independent and identically distributed (iid) with mean zero and finite variance σ^2. The iid assumption excludes lagged dependent variables from ξ_{it}.

The procedure of estimation proposed by Hansen (1999) is sequential and allows one to consider a model with k regimes. For instance, the threshold model with three regimes (two threshold parameters, respectively) is written as:

$$y_{it} = \mu_i + \beta_1 x_{it} I\left(q_{it} \leqslant \gamma_1\right) + \beta_2 x_{it} I\left(\gamma_1 < q_{it} \leqslant \gamma_2\right) + \beta_3 x_{it} I\left(\gamma_2 < q_{it}\right) + \xi_{it} \tag{5}$$

where the threshold parameters γ_j are sorted $\gamma_1 < \cdots < \gamma_k$. We note that the individual effects μ_i are not different in the k regimes. Thus, the regimes are distinguished only by their differing slopes/elasticities β_i.

If we consider a single threshold model as in eq. (4), for a given value of the threshold parameter γ, the slope coefficients β_1 and β_2 can be estimated by OLS. Let us denote $\hat{\beta}_1\left(\gamma\right)$ and $\hat{\beta}_2\left(\gamma\right)$ as the corresponding estimates. Conditional to a value of γ, it is possible to compute the sum of squared errors, denoted as $S_1\left(\gamma\right)$:

$$S_1\left(\gamma\right) = \sum_{i=1}^{N}\sum_{i=1}^{T} \hat{\xi}_{it}^2\left(\gamma\right) \tag{6}$$

The threshold parameter γ is then estimated by minimizing the sum of squared $S_1\left(\gamma\right)$:

$$\hat{\gamma} = \operatorname*{argmin}_{\gamma} S_1\left(\gamma\right) \tag{7}$$

Since this sum of squared residuals depends on γ only through the indicator function $I\left(q_{it} \leqslant \gamma\right)$, it is a step function with at most NT steps, with the steps occurring at distinct values of observed

threshold variable q_{it}. Therefore, the minimization problem in eq. (7) can be reduced to searching over values of γ equalling the (at most NT) distinct values of q_{it} in the sample. Given the value of the estimate $\hat{\gamma}$ it is then possible to make an estimate of the elasticities in the regimes, that is, $\hat{\beta}_1(\hat{\gamma})$ and $\hat{\beta}_2(\hat{\gamma})$ and the estimates of individual effects $\hat{\mu}_i$ [65].

One crucial issue in the estimation of the PTR is to determine if the threshold effect is statistically significant. The hypothesis of no threshold effect in eq. (4) can be represented by the following linear constraint :

$$H_0 : \beta_1 = \beta_2 \tag{8}$$

Under H_0, the model is then equivalent to a linear model (no threshold effect). This hypothesis could be tested using a standard test. If we note S_0 as the sum of squares of the linear model, the approximate likelihood ratio test of H_0 is based on:

$$F_1 = \frac{S_0 - S_1(\hat{\gamma})}{\hat{\sigma}^2} \tag{9}$$

where $\hat{\sigma}^2$ denotes a convergent estimates of σ^2.

Under H_0, the threshold parameter γ is not identified. As a consequence, the asymptotic distribution of F_1 is not standard [66]. Hansen (1996, 1999) suggests to use bootstrapping simulation to determine the asymptotic distribution of the statistic F_1 and to compute its critical values. The same kind of procedure can be applied to more general models (with more than two regimes) in order to determine the number of thresholds. If the P-value associated with F_1 leads to the rejection of the linear hypothesis, we can then discriminate between one and two thresholds. A likelihood ratio test of one threshold versus two thresholds is based on the following statistic:

$$F_2 = \frac{S_1(\hat{\gamma}) - S_2(\hat{\gamma}_1, \hat{\gamma}_2)}{\hat{\sigma}^2} \tag{10}$$

where $\hat{\gamma}_1$ and $\hat{\gamma}_2$ denote the threshold estimates of the model with three regimes and $S_2(\hat{\gamma}_1, \hat{\gamma}_2)$ denotes the corresponding residual sum of squares. The one-threshold hypothesis is rejected in favour of the two-threshold hypothesis if F_2 is larger than the critical value of the non-simulated distribution. The corresponding asymptotic P-value can be approximated via bootstrap simulations (Hansen, 1999).

4.2 Specifications, variables and data source

In our panel threshold model (PTR), the endogenous variable is the household heating expenditures in € per m^2 and the threshold variable is the household income in €. The main exogenous variable is household energy prices in kWh/€. Nevertheless, to consolidate our analysis, we take into account in our estimation the impact of variables other than energy prices. Indeed, it is well supported that residential, in particular, heating energy demand does not depend only on energy prices. In particular, based on the abundant literature dealing with determinants of the demand for energy in the residential sector and depending on the data availability, we add four additional groups of variables explaining the households consumption of energy (**?**, Dubin and McFadden (1984), Halvorsen and Larsen (2001), Labandeira et al. (2006), Nesbakken (2001), Leth-Petersen and Togeby (2001), Meier and Rehdanz (2010)):

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65. Hansen (1999) have explained that it is undesirable for a threshold $\hat{\gamma}$ be selected that sorts too few observations into one or another regime. As a consequence, the optimization domain should be chosen in a way that assures that a minimal percentage of the observations lie in each regime.

66. In particular, it does not correspond to a χ^2 distribution.

— Households characteristics: disposal income (HY020)[67], number of persons (HX040), type of housing tenure (HH020), and the financial ability for a household to maintain a convenient level of warmth (HH050)[68],
— Dwelling properties: presence or not of roof leaks, walls / floors / foundations damp, rot in window frames or floor (HH040), exposure and darkness (SOMBRE), and the length of dwelling tenure,
— Role of appliances: ownership of central or electric heating system (CHAUF),
— Climate areas (ZEAT) : west, north-west, mediterranean[69].

Panel threshold specification that we estimate is written as:

$$
\begin{aligned}
HEE_{it} = \mu_i + \theta_1 INC_{it} + \theta_2 NB_{it} + \theta_3 OW_{it} + \theta_4 TEM_{it} \quad & + \\
\theta_5 LT_{it} + \theta_6 INS_{it} + \theta_7 EX_{it} + \theta_8 HS_{it} + \theta_9 GEO_{it} \quad & + \\
\beta_1 P_{it-1} I\left(INC_{it} \leqslant \gamma_1\right) \quad & + \\
\beta_2 P_{it-1} I\left(\gamma_1 < INC_{it} \leqslant \gamma_2\right) \quad & + \\
\beta_3 P_{it-1} I\left(\gamma_2 < INC_{it}\right) + \xi_{it} &
\end{aligned}
\tag{11}
$$

where variables, acronyms, and data sources are summarized in table 8.

In order to ensure the relevance of our model, in particular the choice of exogenous variables, we start by estimating a panel linear model with fixed effects[70], and create by this way a benchmark model. Indeed, we aim to show that the results of our linear model do not distort those generally obtained in the literature dealing with the determinants of energy demand in the residential sector. This linear panel model is written as:

$$
\begin{aligned}
HEE_{it} = \mu_i + \theta_1 INC_{it} + \theta_2 NB_{it} + \theta_3 OW_{it} + \theta_4 TEM_{it} + \theta_5 LT_{it} \quad & + \\
\theta_6 INS_{it} + \theta_7 EX_{it} + \theta_8 HS_{it} + \theta_9 GEO_{it} + \theta_{10} P_{it-1} + \xi_{it} &
\end{aligned}
\tag{12}
$$

All variables summarized in table 8 are extracted from the EU-SILC database except energy prices which were exogenously calculated by authors in a way to associate to each household a unique price. Indeed, EU-SILC database do not contain information on households energy prices. Calculations are detailed in appendix G. Main descriptive statistics are presented in appendix H.

We note that we use for our estimations a balanced panel composed of 827 households observed during 7 years going from 2008 to 2014.

4.3 Findings and discussion

Below, we start by discussing results of the linear benchmark model in 4.3.1 before turning to interpreting results of the threshold regression in 4.3.2.

4.3.1 Results of the benchmark linear model

Before estimating coefficients, we start by choosing between estimating fixed-effects or random-effects model. We perform the Hausman (1978) test for fixed effects. Under the null hypothesis that individual effects are random, fixed and random effects estimators are similar because both

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67. In this paragraph and in the first column of table 8, we put into parentheses the code of the variable in the EU-SILC database.
68. *Cf.* footnote number [8].
69. The hottest regions in France.
70. We note that the PTR model applies only on model with individual specific fixed effects.

Table 8 – Variables and data sources

Variable	Acronym	Description	Source
Heating expenditures (MCHAUF) [67]	HEE	Endogenous variable. Expressed in € per m^2 [a]	EU-SILC database
-Energy prices	P	Expressed in kWh/€. In order to ensure the absence of endogeneity in our estimations, we consider prices lagged by one period	Authors calculation (*Cf.* appendix G)
Household characteristics			
-Disposal income (HY020)	INC	Expressed in €. Represents the transition variable in the threshold regression	EU-SILC database
-Household number of persons (HX040)	NB	1, 2, 3,...	EU-SILC database
-Type of housing tenure (HH020)	OW	Dummies: 1 if home-owner, 0 otherwise	EU-SILC database
-Financial ability to maintain a convenient level of warmth (HH050)	TEM	Dummies: 1 if yes, 0 otherwise	EU-SILC database
-Length of dwelling tenure	LT	Calculated by authors as the difference between the year of the survey, *i.e.* 2014, and the year in which the household moved into the dwelling (DATENT).	EU-SILC database
Technical proprieties of the dwelling			
-Roof leaks, walls / floors / foundations damp, rot in window frames or floor (HH040)	INS	Dummies: 1 if leaks and rot, 0 otherwise	EU-SILC database
-Exposure and darkness (SOMBRE)	EX	Dummies: 1 if dark, 0 otherwise	EU-SILC database
Role of appliances			
-Ownership of central or electric heating system (CHAUF)	HS	Dummies: 1 if owing heating system, 0 otherwise	EU-SILC database
Climate areas			
-Climate area (ZEAT)	GEO	Dummies: west, north-west, mediterranean	EU-SILC database

a. We use as an acceptable proxy of heating expenditures residential energy expenditures. Indeed, usually space heating costs represent at least half of the household energy bill. For instance, in UK in 2013, on average, around 51% of the theoretical household bill was devoted for space heating costs, 34% for lighting and appliance usage, 12% for water heating, and 3% for cooking costs (DECC, 2014).

are consistent. Under the alternative, these estimators are divergent. Our results lead to rejection of the null hypothesis that random effect provides consistent estimates [71]. We consider, therefore, a panel linear model with fixed effects [72]. Moreover, to take into account the endogeneity of the energy prices, we decided to use Instrumental Variables (IV) with fixed effects. We choose the two-stage least-squares within estimator [73]. We use as instruments energy prices lagged by one period and a dummy variable taking the value 1 when households benefit from the basic energy tariff, *i.e.* the blue tariff (*Cf.* table G.1 from appendix G). In the IV estimation, it is important to conduct a test on whether the excluded instruments are valid or not, thus, whether they are uncorrelated with the error term and correctly excluded from the estimated equation. As a consequence, we perform the Sargan (1958). Its results show that instruments are valid and that the energy prices are endogenous [74]. As a consequence, we estimate the benchmark panel linear model with fixed effects by introducing energy prices lagged by one period in order to remedy for the endogeneity.

Results are presented in table 9. They show that, in addition to prices, the most important determinants of heating energy expenditures are socio-economic characteristics of the household, technical properties of the dwelling, and the climate areas.

More precisely, results show that there is significant and positive relationship between energy prices and energy expenditures according to which when energy prices increase by 10% heating expenditures increase by 11.6%. When looking at the literature, we should expect, rather, a neg-

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71. The overall statistic test is equal to 0.0571.
72. Output of the random effects estimation are available upon request.
73. *Cf.* Baltagi (2008) for more information about panel-data models with endogenous covariates.
74. The p-value of $\chi 2$ statistic is equal to zero.

ative elasticity relating energy prices and energy expenditures, *i.e.* when energy prices increase, energy expenditures decrease (*Cf.* appendix H for a brief literature review on energy price and income estimates of elasticities). Nevertheless, although our results do not corroborate previous estimates, it supports the largely observed phonemenon according to which the steady increase in energy prices over a prolonged period has increased overall price levels and has led to inflation, which have forced consumers to increase spending, including energy expenditures (Wang, 2013). In this context, as also shown by our results, the proportion of energy expenditures increase is usually equal to the proportion of energy prices variations, *i.e.* 10% increase in energy prices leads to 11.6% increase in energy expenditures. On the empirical level, Merceron and Theulière (2010) show that in France the share of energy expenditures [75] in the total household budget has remained stable and equal to 8.4% over the time period going from 1970 to 2008.

In sum, our result with respect to the energy price-expenditures elasticity reflects a long-run effect of energy prices increase where inflationary price effect dominates leading, thereby, to energy expenditures increase.

As for other determinants of energy expenditures related to household characteristics, our results interestingly show that a 10% income increase induces 4.40% decrease of heating expenditures. Once again, this result goes against statement of the literature. As in the case for price elasticity, we argue that this negative relationship between income and energy expenditures reflects a long-run effect where, in the context of steady energy prices increase, an income increase pushes consumers to seek for implementing strategies to decrease their energy expenditures. This may involve mainly the purchase of more efficient energy equipments, as a form of a long-run investment which will induce energy consumption, thus, energy expenditures decrease.

In addition to price and income effects, results also show that there is a significant positive correlation between the number of persons of the household and the demand for heating. When the number of persons increase, heating consumption, thus, expenditures also increases. Also, as expected, there is a negative and significant correlation between the ability of the household to maintain a convenient level of warmth and energy expenditures.

As for the relationship between dwelling characteristics and energy expenditures, results show that bad technical properties of the dwelling, like for example insulation problems, *i.e.* presence of roof leaks, foundations damp, or rot in window frames or floor as well as darkness problem, increase heating expenditures. Less efficient dwellings need much more energy to be heated than efficient ones.

Finally, when looking to the impact of climate areas, results show that there is a negative and rather statistically significant correlation between living in hot or mild climate regions, *i.e.* west, south-west, and mediterranean, and energy expenditures. Obviously, heating needs in the winter are less important in such regions.

4.3.2 Results of the threshold model

Before estimating a threshold regression, a first step consists in determining the number of regimes or, equivalently, testing for the existence of threshold(s). Towards that end, we use the sequential procedure proposed by Hansen (1999). Therefore, the model is estimated, allowing for sequentially zero, one, two and three thresholds. For each specification, the tests statistics F_1, F_2 and F_3, along with their bootstrap P-values, are determined. The results of these tests, wherein the threshold variable the income INC_{it}, are reported in table 10.

When testing for the presence of one single threshold, we find that F_1 is significant, with a boot-

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75. Merceron and Theulière (2010) consider heating and transport energy expenditures.

Table 9 – Results of linear panel model with fixed effects - Balanced panel 2008-2014

Within estimates	Coefficient [a] t − statistic [b]
Income (INC_{it})	-0.044 (-2.256***)
Household number of persons (NB_{it})	0.054 (6.232***)
Home owner (OW_{it})	0.116 (4.856***)
Financial ability to maintain a convenient level of warmth (TEM_{it})	-0.100 (-2.022**)
Length of dwelling tenure (LT_{it})	0.001 (2.022**)
Leaks and rot (INS_{it})	0.123 (3.753***)
Exposure and darkness (EX_{it})	0.092 (2.351**)
Ownership of heating system (HS_{it})	0.045 (0.966)
West (GEO_{it})	-0.091 (-3.243***)
South-West (GEO_{it})	-0.061 (-1.870*)
Mediterranean (GEO_{it})	-0.052 (1.502)
Energy prices (P_{it-1})	0.116 (1.951)*
RSS	1777
Number of observations	4962
Number of households	827

a. Dependent variable is the logarithm of heating expenditures per m^2. All variables are expressed in logarithm.
b. The t-statistics are in parenthesis. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 10 – Tests for threshold effects

	Threshold variable: household income (INC_{it})
Test for single threshold [a]	
F_1	12.349
P-value	0.09
(10%, 5%, 1% critical values)	(12.079, 12.932, 15.795)
Test for second threshold [a]	
F_2	4.941
P-value	0.735
(10%, 5%, 1% critical values)	(12.140, 13.897, 17.936)

a. P-value and critical values are computed from 100 and 200 bootstrapping replications. F_1 denotes the Fisher type statistic associated to the test of the null of no threshold against one threshold and F_2 corresponds to the test one threshold against two thresholds.

Table 11 – Threshold estimates and confidence interval

	Estimate	95% confidence interval
$\hat{\gamma_1}$	9.270 [a]	[9.180, 10.746] [b]

a. Since all variables are expressed in logarithm, this value represents the logarithmic expression of the income threshold variable. As a consequence, expressed in level, the threshold level is qual to 10 614.75€.
b. The confidence interval for the threshold parameters corresponds to the no rejection region of confidence level 95% associated to the likelihood ratio statistic for test on the values of the threshold parameters (Hansen, 1999). This confidence interval can be not symmetric.

strap P-value equal to 0.09. This constitutes an evidence that the relationship between heating expenditures and energy prices is non-linear. The test for a double threshold, F_2, is not significant, with a bootstrap P-value equal to 0.735. We, therefore, stop the sequential procedure at this stage and conclude that there is only one threshold.

The estimation of the value of the threshold and associated confidence interval are given in table 11 [76]. It shows that threshold, expressed in logarithm, is equal to 9.27. This value corresponds to an income (cu) equal to 10 614.75€. The asymptotic confidence intervals for the threshold are tight, $i.e.$ [9.180, 10.746], indicating little uncertainty about the nature of this division of households according to this estimated value of the threshold.

Now, after proving the existence of threshold and determining its value, we can estimate the threshold regression. The coefficients estimates and the corresponding t-statistic are displayed in table 12. Those of primary interest are the ones associated to the energy prices variable. The estimates suggest that, as in the benchmark linear model but unlike the statments of the literature, the relationship between energy prices and expenditures is positive. We argue that it reflects the long-term effect of energy prices inflation leading to energy spending increase. In particular, when energy prices increase by 10%, energy expenditures increase by 2.5% to 9.8% depending on household income level ($Cf.$ figure I.1 from appendix I for comparative plot). More precisely, households having an income lower than the threshold value, $i.e.$ $INC_{it} \leqslant 10\ 614,75$€, have a greater energy price elasticity equalling 9.8%. This implies that, $a\ priori$, the impact of prices fluctuations is more important in the case of fuel poor or fuel vulnerable households which will probably restrain their heating consumption and can, as a consequence, exacerbate their situation. In other words, households with income level greater than the threshold are less subject to negative consequences of price increase on heating expenditures. Indeed, their estimated elasticities do not go beyond 2.5%.

To ensure that households with high level of energy price elasticity are fuel poor, we look at the profile of households belonging to each regime. Results show that 53.99% of households belonging to the first regime, to which is associated with a high elasticity, $i.e.$ 9.8%, are fuel poor and that only 14.87% of households belonging to the second regime with low elasticity, $i.e.$ 2.5%, are fuel poor, according to the LIHC m^2 indicator. This result corroborates our hypothesis stipulating that the sensitivity of fuel poor households to energy prices variations is more important than that of non fuel poor.

As for the other coefficients, results show that they go the same line as the idea that the most important determinants of heating energy expenditures are the socio-economic characteristics of the household, the technical properties of the dwelling, and the climate areas. In particular, when household income increase by 10%, heating expenditures decrease by 8.8% ($Cf.$ figure I.1 from appendix I for comparative plot). As in the benchmark linear model, we expect that such decrease is induced by long-run investment in energy efficiency strategies. For instance, after an income increase households will purchase more efficient energy equipments which are more expensive compared to conventional ones but which permit to carry out long-run energy expenditures savings. On the other hand, the number of persons in the household and the type of dwelling tenure, $i.e.$ home-owner or not, are positively correlated to heating expenditures. Big family and households owning their dwelling are expected to have more important heating expenditures. Moreover, as in the linear benchmark model, results show that when the dwelling is suffering from darkness or insulation problems heating expenditures increase. Finally, the impact of climate zone on heating expenditures is rather statistically significant showing that energy needs of households living in hot regions are less important.

76. The threshold variable is trimmed off 5% at both sides to be searched for the threshold estimator.

Table 12 – Regression estimates: one threshold model - Balance panel 2008-2014

Variable	Coefficient (t-statistic)
Income (INC_{it})	-0.088 (-4.197***)
Household number of persons (NB_{it})	0.056 (6.597***)
Home owner (OW_{it})	0.108 (4.403***)
Financial ability to maintain a convenient level of warmth (TEM_{it})	-0.118 (-2.661***)
Length of dwelling tenure (LT_{it})	0.001 (2.250**)
Leaks and rot (INS_{it})	0.114 (3.505***)
Exposure and darkness (EX_{it})	0.076 (2.034**)
Ownership of heating system (HS_{it})	0.021 (0.467)
West (GEO_{it})	-0.101 (-3.691***)
South-West (GEO_{it})	-0.069 (-2.244*)
Mediterranean (GEO_{it})	-0.042 -1.234
Regime 1: $P_{it-1}I\left(INC_{it} \leqslant 9.27\right)$	0.098 (2.932**)
Regime 2: $P_{it-1}I\left(INC_{it} > 9.27\right)$	0.025 (2.403**)

5   Scope of findings and policy implications

Our findings open once again the debate about two crucial points.

The first one deals with the multidimensionality of fuel poverty and the associated overlapping factors that render difficult the identification of groups of fuel poor households and their characterization. In fact, based on the existing several measures of fuel poverty, it is possible to determine groups of fuel poor households but, as shown in section 3, results are usually variable and call for caution. Some people situated outside groups of fuel poor households according to one measure can belong to these groups according to a second measure. In this context, the implementation of public policies devoted to fighting fuel poverty can become difficult. Ideally, these public policies should be defined in a way to not only remedy fuel poverty but also to prevent it.

The second point highlights that the income is a key determinant of fuel poverty, thus, that there is an obvious causal relationship between monetary poverty and fuel poverty. In this context, Watson and Maître (2015) examine the overlap between fuel poverty and monetary poverty and argue that fuel poverty is better regarded as an aspect of low living standards rather than being a distinct dimension of deprivation. Fundamentally, this means that, in addition to public policies specially devoted to fighting fuel poverty, other policy responses to monetary poverty can represent an additional lever for overcoming fuel poverty.

Within the framework of reflexion about fuel poverty in France under The Act of 17 August 2015 on energy transition, these findings call for two main recommendations:

— Ensure the identification of fuel poor households:

From practical point of view, identification of fuel poor households is a difficult and costly task. Morestin et al. (2009) and Dubois (2012) argue that the selecting criteria underlying the identification process should be well defined to ensure targeting households which are really fuel poor. In this context, it is important according to our point of view to distinguish fuel poor from fuel vulnerable households. In contrast to fuel poverty which represents a static situation giving a snapshot of the household energy state at a given moment, fuel vulnerability takes into account the dynamic dimension inherent to fuel poverty and focuses on the sensitivity of a given household to a risky situation induced by a change in one or multiple variables which modifications can affect it situation [77], thus, it focuses on the risk for a household to be pushed into the fuel poverty.

— Review existing public policies and expand the pallet of remedies:

In France, curative measures to help overcoming fuel poverty was implemented since 1980 with the signature in 1985 of a contract [78] between the two main energy suppliers EDF and GDF and the French Government creating an Energy Solidarity Fund. This measure was followed by the creation of the social tariff for electricity, *i.e.* "*le Tarif de Première Nécessité*" (TPN), and the social tariff of gas, *i.e.* "*le Tarif Spécial de Solidarité*" (TSS), in 2004 and 2008, respectively. Curative measures also include some special protection measures implemented for the case where fuel poor households benefiting from social tariffs are unable to pay their energy bills. In addition to curative measures, preventive ones were also recently developed. They mainly focus on encouraging dwelling energy efficiency, *i.e.* diagnostic of energy use, financial support to renovation measures, as for instance the program "Habiter Mieux" conducted by the National Housing Agency [79].

Although representing a crucial step in fighting fuel poverty, these policies are not sufficient. The impact of curative measures is usually short in time and limited because they suffer from inertia and lack of coordination and clarity. Indeed, in addition to be uncorrelated with energy prices variations, they usually are not well targeted. Preventive measures offer an interesting perspective for tackling the problem from a long-term point of view but households are not usually sufficiently informed to find interesting the opportunity to make dwelling retrofit investments [80].

We support that preventive and curative measures are complementary but that the latter should be reviewed. A consensual proposal that is currently discussed in France is to gather in one ticket all financial curative measures, or at least, social energy tariffs to ensure their visibility. We also support that a deep reflexion on how to implement preventive measures dealing with dwelling energy efficiency should be conducted. It should target fuel poor in priority. Finally, since curative as well as preventive measures are basically devoted to offer directly or indirectly financial support to fuel poor households, we suggest to associate reflexion about solutions to fuel poverty problem with the one dealing with the definition of public policies devoted to fight monetary poverty.

6   Conclusion

Fighting fuel poverty must take into account its multidimensional character which makes the identification and the characterization of groups of fuel poor households difficult. Policies devoted to fight fuel poverty in France involving curative financial support should be reviewed and those

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77. Socio-economic characteristics, dwelling attributes such as home energy efficiency, geographical location, or also of other exogenous variables like for example energy prices fluctuations as analyzed in our study.

78. The "*Convention Solidarité Énergie*" of 1985.

79. "*Agence Nationale de l'Habitat*".

80. We note here that in France some preventive measures was criticized because not suitable for fuel poor households, *i.e.* interest-free interest eco-loans, and sustainable development tax credits, already not able to pay their energy bills.

involving preventive actions enhanced. Both policies should also be reassessed bearing in mind that usually the fuel poverty problem is rather a poverty, or equivalently, a general deprivation problem.

Besides, an unresolved crucial issue inherent to the debates on fuel poverty deals with how to fund public policies devoted to fight it. Making all energy consumers contribute *via* direct taxation or taxation of their energy consumption can be unfair for fuel poor households. They should be identified in advance and either exonerated from tax payment or compensated *ex post*. Reflexion about this question is still pending.

A Summary of fuel poverty measures, their advantages, and their drawbacks

Table A.1 – Summary of fuel poverty measures, their advantages, and their drawbacks

Main reference	Definition	Advantages	Drawbacks
		1. Objective factual measures	
		Expenditures-based measures	
UK Government based on Boardman (1991)	The 10% indicator: — Calculation: $$\text{FP ratio} = \frac{\text{Theoretical fuel costs}}{\text{Income before housing costs}}$$ — Rule: — if FP ratio $\geqslant$ 10% $\Rightarrow$ the household is fuel poor, — if FP ratio $<$ 10% $\Rightarrow$ the household is not fuel poor,	— The comparison between theoretical and actual energy consumption permits to take into account the under-consumption phenomenon.	— Based on obsolete UK energy expenditures threshold going back to 1988, — Based on theoretical rather than actual energy spendings, — Do not take into account plausible restriction practices, — Do not take into account income level of affluent households, — Do not take into account constrained spendings.
Hills (2011)	The After Fuel Cost Poverty (AFCP) indicator: Fuel poverty if [Equivalised (Income − Housing costs − Domestic fuel costs)] < [60% equivalised (Median income − Housing costs − Domestic fuel costs)]	— Taking into account a part of constrained expenditures, i.e. housing costs, — Identification of the aggravating effect of fuel poverty on income poverty.	— Plausible misleading classification of households with very low income into the group of fuel poor regardless of their fuel needs, — Possible confusion between fuel and monetary poverties.
Hills (2011, 2012)	The Low Income High Costs (LIHC) indicator: Fuel poverty if [Equivalised (Disposal income − 60% (equivalised median disposal income)] < and Equivalised fuel cost spending $\geqslant$ Required national median fuel spending	— Definition of two thresholds to identify fuel poor households: one dealing with the disposal income and the other with fuel spending $\Rightarrow$ Distinguishing fuel and monetary poverties.	— Not based on the constrained income, — Do not take into account plausible restriction behavior of some households.
		The restriction behavior measure	

Table A.1 – Complete the previous page

Main reference	Definition	Advantages	Drawbacks
ONPES cited in Dutreix et al. (2014) and ONPE (2014)	The restriction behavior indicator: Theoretical fuel consumption — Actual fuel consumption	— Permits to target households who have a cost analysis suitable for dwelling fuel investment.	— Theoretical energy expenditures are usually difficult to assess.
		Consensual social measures	
Healy and Clinch (2002) and Nussbaumer et al. (2011)	Also *Cf.* summary of Healy and Clinch (2002) and Nussbaumer et al. (2011) presented in the section entitled "Composite indices" in this table) Possibility of using different objective indicators: — The presence of damp walls and/or floors, — The lack of central heating, — The presence of rotten window frames, — The access to an electricity system, — The household appliance ownership.	— Capture wider elements of fuel poverty question especially when included in composite indices.	— Plausible irrelevant results if used irrespective to objective measures.
		2. Subjective self-reported measures	
Healy (2003), EPEE (2006), and INSEE ENL (2006)	Possibility of asking different questions: — Do you suffer from thermal discomfort? — Do you experience difficulty to pay utility bills (over the past period)? — Do you feel to be able to afford energy? — Are you satisfy with heating facilities?	— Possibility to be completed by qualitative surveys/interviews to better understand the characteristics of fuel poor households.	— Results should be interpreted with caution, — Plausible contrasting results compared to those of objective measures mainly with respect to the identification of fuel poor households.
		3. Composite indices	
Healy and Clinch (2002)	Composite weighted index based on the combination of six consensual social indicators which: — Are split into two sub-groups: subjective self-reported and objective factual indicators, — Pertaining to household finances (fuel and utility bills), the building fabric (presence of damp or rot), and the dwelling heating system.	— Consider the multidimensional character of fuel poverty, — Associate objective and subjective criteria, — More suitable for cross-countries comparison (than 10% indicator).	— Assignments of weights to each indicator incorporated into the composite indice is somewhat arbitrary, — Plausible results variability depending on the weight assigned to each indicator.
Nussbaumer et al. (2011)[81]	Composite index so-called Multidimensional Energy Poverty Index (MEPI) focusing on the deprivation of access to modern energy services. It is composed of five dimensions representing basic energy services and six weight/indicators.	— Consider the multidimensional character of energy poverty, — Present a solid methodological foundations (literature on multidimensional poverty).	— Assignments of weights to each indicator incorporated into the composite indice is somewhat arbitrary, — Exclude subjectif criteria.
			Cf. next page

81. This paper focus on the global question of energy poverty in African developing countries rather than on the specific issue of fuel poverty as perceived in developed countries.

Table A.1 – Complete the previous page

Main reference	Definition	Advantages	Drawbacks
Thomson and Snell (2013)	Composite weighted index based on the combination of three proxy indicators namely the presence of arrears on utility bills in last twelve months, the presence of a leaking roof, damp walls or rotten windows, and the ability to pay to keep the home adequately warm.	— Considering the multidimensional character of fuel poverty, — Associating objective and subjective criteria, — More suitable for cross-countries comparison (than 10% indicator).	— Assignments of weights to each proxy indicator is somewhat arbitrary, — Plausible results variability depending on the weight assigned to each indicator.
Fabbri (2015)	Composite index so-called Building Fuel Poverty Index (BFP) aiming at assessing the relation between building energy performance, dwelling habits, and fuel poverty risk.	— Analyzing the causal relationship between fuel poverty and building energy performance, — Taking into account households income.	—

B   Technical description of calculation of fuel poverty rates

EU-SILC database covers the period going from 2004 to 2013. Nevertheless, to calculate annual fuel poverty rates, we consider the period going from 2008 to 2013. Indeed, from 2004 to 2008, the quality of data describing energy expenditures is bad. For example, in 2006, 10 036 households have been asked about their energy expenditures but only 2 146 on 7 890 observations were reported[82].

In the EU-SILC database, we referred to the following variables, listed below by their acronyms, to calculate fuel poverty rates according to 10% and LIHC indicators :

— Variables used to calculate energy/fuel costs:
  — MENERG: annual amount of electricity and gas expenditures not included in rental charges.
  — MELEC: annual amount of electricity expenditures not included in rental charges.
  — MGAZ: annual amount of gas expenditures not included in rental charges.
  — MCHAUF: annual amount of gas expenditures not included in rental charges.
  — MIENRG: annual amount of electricity and gas expenditures included in rental charges.
  — MIELEC: annual amount of electricity expenditures included in rental charges.
  — MIGAZ: annual amount of gas expenditures included in rental charges.
  — MICHAUF: annual amount of gas expenditures included in rental charges.

— Variables referred to calculate the equivalizid income:
  — HY020N: disposal income at the year N.
  — HX050: number of household consumption unities.
  — SURFACE: the surface of the dwelling.

B.1   Calculation of fuel poverty rates according to the 10% indicator

The 10% indicator is calculated according to the following formula (*Cf.* table A.1 from appendix A):

$$\text{10\% indicator} = \text{FP} = \frac{\text{Fuel costs}}{\text{Income before housing costs}} \qquad \text{(B.1)}$$

— if FP ratio $\geqslant$ 10% $\Rightarrow$ the household is fuel poor.
— if FP ratio $<$ 10% $\Rightarrow$ the household is not fuel poor.

One drawback of the 10% indicator is to over-estimate the extent of fuel poverty inside the population by including in groups of fuel poverty households having a high level of income. To overcome this critics, the ONPE (2014, 2015) suggest to include in calculation only households having an income (cu) lower than the threshold of the third decile of income (cu).

As a consequence, in our study, the population of households have been firstly sorted according to its income (cu) and then divided into 10 equal groups each one containing 10% of the population, *i.e.* deciles calculation. Then, the annual threshold of the third income (cu) decile was determined. Only households having an income (cu) level lower than this threshold have been retained when determining fuel poor group of households. Table B.1 below presents thresholds of the third income (cu) decile that we have calculated in comparison with the national thresholds calculated by the INSEE (2014)[83] :

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82. *Cf.* dictionary of codes 2006, p. 124
83. `http://www.insee.fr/fr/themes/tableau.asp?ref_id=NATnon04249`. Accessed in August 29, 2016.

Table B.1 – Threshold of the third decile of income (*cu*)

Year	EU-SILC sample threshold	National threshold [a]
2008	15 539 €	17 230 €
2009	15 957 €	17 160 €
2010	16 300 €	17 000 €
2011	16 428 €	16 830 €
2012	16 986 €	16 770 €
2013	17 079 €	16 850 €

a. These threshold do not represent the exact value of national threshold of the third decile of income (*cu*) but rather the standard of living of population having an income level situated between the national third and the fourth deciles of income. They are calculated in constant €2013.

A household is fuel poor if:

$$\frac{\text{MELEC} + \text{MGAS} + \text{MCHAUF} + \text{MIELEC} + \text{MIGAS} + \text{MICHAUF}}{\text{HY020N}} \geqslant 10\% \qquad \text{(B.2)}$$

and

$$\text{Income } (cu) \quad = \quad \frac{\text{HY020N}}{\text{HX050}} \qquad \text{(B.3)}$$

$$< \quad \text{Threshold of the third decile of income}$$

B.2 Calculation of fuel poverty rates according to the LIHC indicators

The LIHC fuel poverty rate is calculated according the following formula (*Cf.* table A)

$$\begin{cases} \text{Equivalised disposal income} \leqslant 60\% \text{ (Equivalised median disposal income)} & \text{(B.4)} \\ \text{Equivalised fuel expenditures} \geqslant \text{Required national median fuel expenditures} \end{cases}$$

Equivalised fuel expenditures are calculated by dividing fuel expenditures by the number of consumption unity in the case of LIHC (*cu*) indicator and by the surface of the dwelling in the case of the LIHC (m^2) indicator :

Table B.2 – Equivalilzed median income and fuel expenditures

Year	60% of equivalised median disposal income	Median of equivalized fuel expenditures
2008	11654 €	702 €
2009	12076 €	761 €
2010	12314 €	771 €
2011	12460 €	801 €
2012	12786 €	800 €
2013	12728 €	860 €

— LIHC (*cu*) indicator:

$$\text{Equivalised fuel expenditures } (cu) \quad = \qquad \text{(B.5)}$$
$$\frac{\text{MELEC} + \text{MGAS} + \text{MCHAUF} + \text{MIELEC} + \text{MIGAS} + \text{MICHAUF}}{\text{HX050}}$$

— LIHC (m^2) indicator:

$$\text{Equivalised fuel expenditures } (m^2) = \frac{\text{MELEC} + \text{MGAS} + \text{MCHAUF} + \text{MIELEC} + \text{MIGAS} + \text{MICHAUF}}{\text{SURFACE}} \quad \text{(B.6)}$$

Equalized income is calculated as follows:

$$\text{Income } (cu) = \frac{\text{HY020N}}{\text{HX050}} \quad \text{(B.7)}$$

Table B.2 gives values of the median fuel expenditures and of 60% of equivalised median disposal income calculated on the basis of EU-SILC work sample.

C Potential drivers of fuel poverty: summary of the literature[84]

Table C.1 – Potential drivers of fuel poverty: summary of the literature

Drivers	Modality	Dominant expected effect
Household characteristics		
- Type of the household	Single; Childless couple; Couple with child; Single-parent family.	The presence of children increases energy needs, thus, the probability of falling into fuel poverty.
- Sex	Men; Women.	Women, mainly single, having child, and unemployed are usually fuel poor.
- Number and age of children	Number=[0, 1, 3...]; Age: young age or not.	The presence of children increases energy needs, thus, the probability of falling into fuel poverty.
- Socio-professional category	Farmer; Artisan; Trader; Company-manager; Higher intellectual profession; Intermediate profession; Employee, etc,...	A high socio-professional category reduces the risk of being fuel poor because it increases the probability of having a high income level.
- Income	> or < poverty threshold, i.e. 60% median income.	A high income level reduces the risk to be fuel vulnerable because its ensures the ability to afford energy[85].
- Employment status	Employed; Unemployed; Retired; Student.	Employment ensures income, thus the ability to afford energy, and reduces the risk to fall in fuel poverty.
- Education level	High; Intermediate; Low; No diploma.	High educational attainment reduces the risk to be a fuel poor since it increases the probability of being employed and having a high income.
- Occupancy status	Home-owner; Private tenant, Public-housing tenant.	Home-owners fall less frequently in fuel poverty.
Dwelling attributes		
- Type	Apartment; Detached dwelling.	The fuel poverty risk increases when the household is living in a detached dwelling.
- Construction date	Before 1974; After 1974.	In France, 1974 represents the date of the introduction of the first housing thermal regulation. Dwellings constructed after this date are more energy efficient which may decrease the fuel poverty risk for people living inside.
- Housing area	Area in m^2.	Living in large dwelling increases the probability to fall in energy poverty because energy needs increase are more important.
- Heating system	Individual electric convectors; Individual boiler; Collective boiler; Mixed heating system; Wood stove or coal; No heating system.	Individual boiler, wood stove or coal are usually associated with a high probability of being fuel poor.
- (Heating) energy source	Electricity; City gas; Fuel oil; Butane, propane or gas tank; Coal; Wood; Renewable energy.	High energy prices increase the risk of being fuel poor regardless the source of energy used.

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Table C.1 – Complete the previous page

Drivers	Modality	Dominant expected effect
- Other dwelling attributes	Damp; Leaks; Ventilation system; Dark,...	The presence of damp, leaks, or a broken ventilation system usually exacerbate an already existing fuel poverty situation.
Other drivers		
Climate characteristics	Mediterranean; Continental; Oceanic; Temperate.	Living in a hot region decreases heating energy needs, therefore, the risk to be fuel poor[86].
Vehicle ownership	Yes; No.	Owing a vehicle increases the probability of being fuel poor because of energy commuting expenditures.

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86. Conversely, we note that energy needs can be high in a hot region because of the use of air conditioning system (*Cf.* Fouquau and Bessec (2008)).

D Technical description of preliminary management of the dataset before running the MCA

D.1 General presentation

By definition, MCA is suitable for qualitative variables. In our initial dataset, 11 variables are nominal and 7 are quantitative, *i.e.* "Age (AGEPR)", "Monthly total financial endowments (TOTREVEN)", "Monthly total housing costs (HH070)", "Area of the dwelling (SURFACE)", "Dwelling acquisition date (DATACH)", "Number of employed persons (NACTOCCCUP)", and "Number of children (NENFANTS)". To be able to capitalize information contained in these quantitative variables when running our MCA we proceed as follows.

First, we incorporate in the MCA the variables "Number of employed persons (NACTOC-CUP)" and the "Number of children (NENFANTS)" as quantitative. Indeed, in some cases, it is possible to expand MCA analysis by incorporating a limited number of quantitative/continuous variables. They, therefore, have the status of supplementary variables in contrast with the qualitative variables which are incorporated in the MCA as active variables. This implies that quantitative supplementary variables do not contribute to the inertia (variance) of axes of the MCA. They only permit to refine the interpretation of results, *i.e.* better mapping of profiles of households.

Second, since MCA can accommodate quantitative variables by recoding them as categorial, we introduce the 5 remaining quantitative variables, *i.e.* variables "Age (AGEPR)", "Monthly total financial endowments (TOTREVEN)", "Monthly total housing costs (HH070)", "Dwelling surface (SURFACE)", "Dwelling acquisition date (DATACH)" after cutting them into classes. By this way, they become categorial and can be introduced in the MCA as active variables. Subsection D.2.1 below presents how we have defined classes for each one of them.

In sum, as presented in table 4 from subsection 3.2, we run the MCA by considering 16 active qualitative/categorial variables and 2 supplementary quantitative variables, where 5 of the 16 qualitative/categorial variables represent basically quantitative variables which have been coded into classes.

Within the same context of variables reorganization, we have grouped and defined new levels for the variable "Socioprofessionnal category (CSMEN)". Indeed, in the original dataset, this variable was initially associated with 42 levels with a very small number of observations for some ones of them. We finally retained 5 levels as detailed in subsection D.2.2 below. This subsection also gives a presentation of preset levels associated with the other qualitative variables of the original dataset.

D.2 Presentation of levels of qualitative/categorial variables included in the MCA

D.2.1 Classes assigned to quantitative variables

— Variable 1. Age (AGEPR)
  — *6 levels*: <20years, [21-40years), [41-60years), [61-80years), [81-90years), >90years.

— Variable 2. Surface (SURFACE)
  — *6 levels*: <20m2, [25-40m2), [40-70m2), [70-100m2), [100-150m2), >150m2.

— Variable 3. Date of purchase (DATACH)
  — *6 levels*: <Ther reg 1, >Ther reg 1974, >Ther reg 1988, >Ther reg 2000, >Ther reg

2005, >Ther reg 2012. "Ther reg" means "Thermal regulation". Therefore, the date of purchase of the dwelling was coded by referring to dates of thermal regulation in France. This permits to define this variable as a proxy of dwelling energy efficiency.

— Variable 4. Monthly total financial endowments (TOTREVEN)
  — *6 levels*: I[0,2e+03), I[2e+03,4e+03), I[4e+03,6e+03), I[6e+03,8e+03), I[8e+03,1e+04), I>1e+04.

— Variable 5. Monthly total housing costs (HH070)
  — *5 levels*: R[0,500), R[500,1e+03), R[1e+03,1.5e+03), R[1.5e+03,2e+03), R>2e+03.

D.2.2 Levels associated to qualitative/categorial variables as in the original database

— Variable 6. Type of the household (HX060)
  — *10 levels*: Single, Couple <65 no children, Couple >65 no children, Other no children, One-parent family, Couple 1 child, Couple 2 children, Couple 3 children, Other with children, Indet.

— Variable 7. Sex of the household reference person (SEXEPR)
  — *2 levels*: Men, Women.

— Variable 8. Socio-professionnal levels of the household (CSMEN)
  — *42 levels before grouping into new classes*: Farmer S, Farmer M, Farmer G, Artisan, Trader, Entrepreneur>10, Professions, Manger PF, Scientific job, Prof of arts and entertainment, Manger F, Engineer, Professor, Inter job health, Religious Clergy, Inter job AFP, Inter job ACE, Technicians, Foremen, Civil empl, Police officer/Soldier, Worker adm firm, Employ trade, Worker sdp, Worker QTI, Worker QTA, Driver, Workers qual m, Workers NQTI, Workers NQTA, Workers ag, Prev AE, Prev ACCE, Prev cadres, Prev PI, Prev emply, Prev worker, Unemployed, Military, Student, Other no activ <60, Other no activ >60.
  — *5 levels after grouping into new classes*: Farmer, Artisan/Merchant, Engineer/Manger, Employee/Worker, Unemployed.

— Variable 9. Ownership of cars (HS110)
  — *3 levels*: Yes, No (expensive), No (other reason).

— Variable 10. Poverty indicator at the threshold of 60% (HX080)
  — *2 levels*: Not poor, poor.

— Variable 11. Type of housing/dwelling (TYPLOG)
  — *7 levels*: Farm/Detached house, Town detached house, Apart. (2 apart. building), Apart. (3-9 apart. building), Apart. (>10 apart. building), Caravan, Other.

— Variable 12. Type of housing tenure (HH021/HH020)
  — *5 levels*: Owner1, Owner2, Tenant, Subtenant, Free accommodation.

— Variable 13. Ownership of central or electric heating system (CHAUF)

— *2 levels*: Yes, No.

— Variable 14. Indoor difficult to heat (DIFCHAUF)
    — *2 levels*: Yes, No.

— Variable 15. Roof leaks, walls / floors / foundations damp, rot in window frames or floor (HH040)
    — *2 levels*: Yes, No.

— Variable 16. ZEAT residence (ZEAT)
    — *8 levels*: Ile-de-France, Bassin parisien, Nord, Est, Ouest, Sud-Ouest, Centre-Est, Méditerranée.

E   Complementary results of MCA analysis - Confidence ellipses around categories/levels of MCA variables
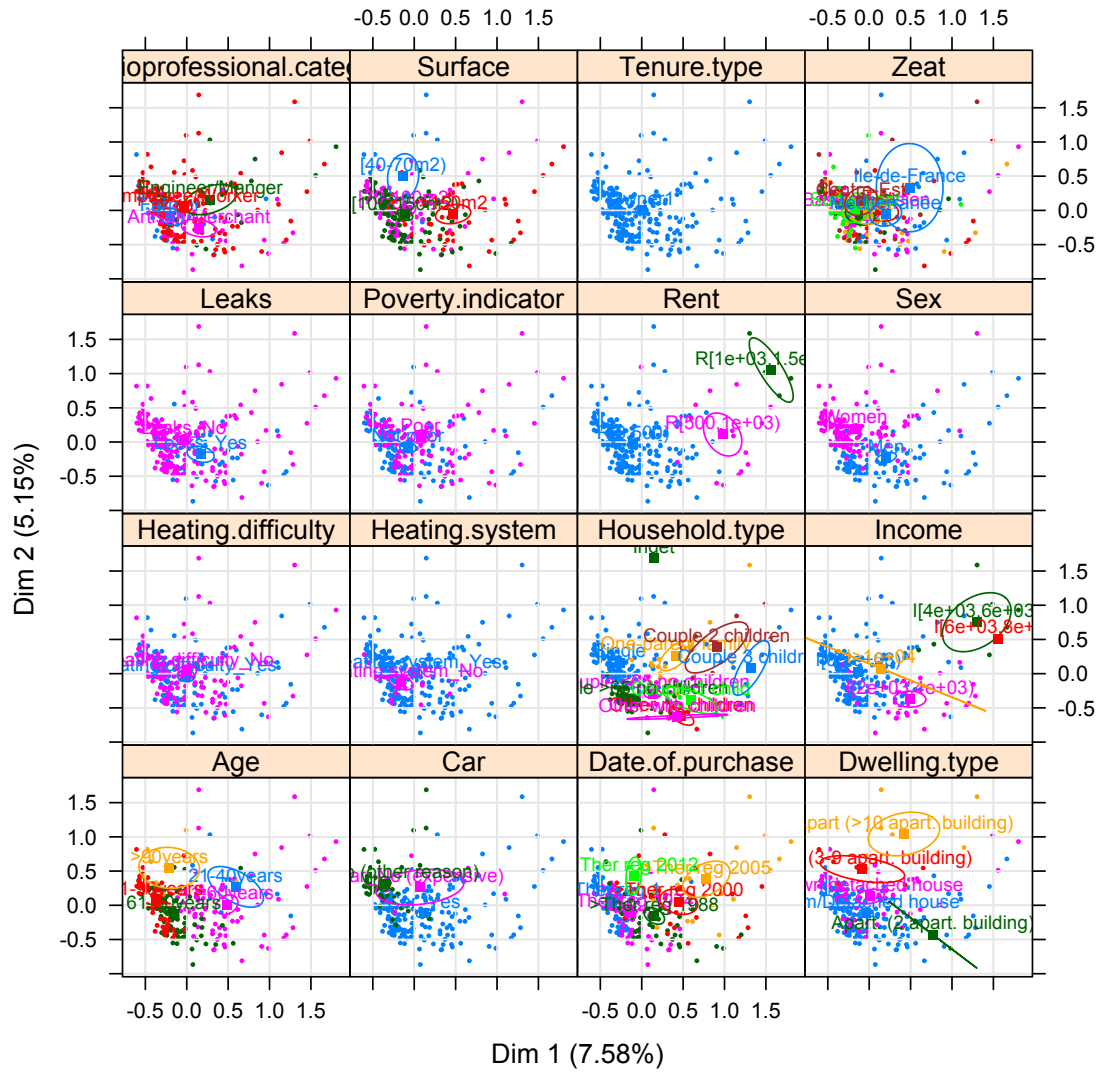

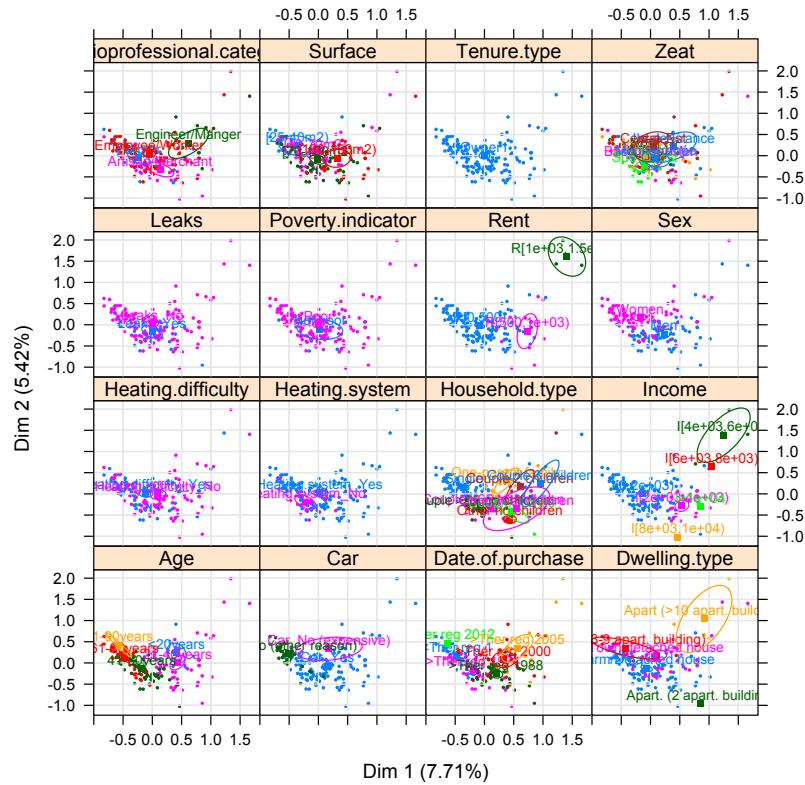Figure E.1. Confidence ellipses around categories/levels of MCA variables - 10% indicator

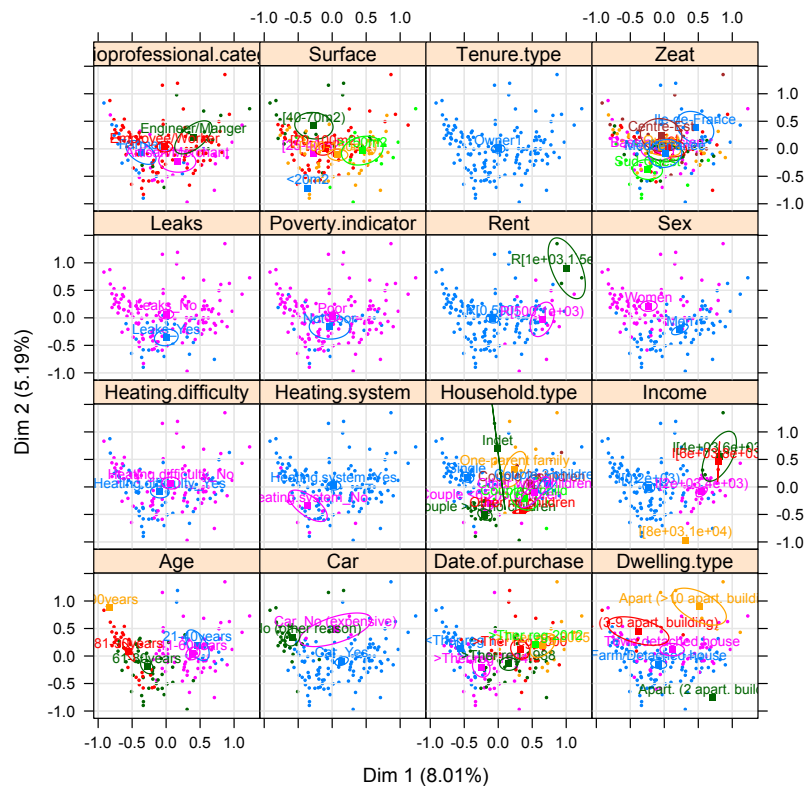Figure E.2. Confidence ellipses around categories/levels of MCA variables - LIHC (cu) indicator

Figure E.3. Confidence ellipses around categories/levels of MCA variables - LIHC (m^2) indicator

F   Brief presentation of Pégase, EU-SILC, and PHÉBUS databases

F.1   Pégase database

Pégase database ("*Pétrole, Électricité, Gaz et Autres Statistiques de l'Énergie*") stores and distributes French energy statistics collected by the Department of Observation and Statistics ("*Service de l'Observation et des Statistiques*" (SOeS)). The new methodology of dissemination of detailed statistics is based on Beyond 20/20 format which is also used by the International Energy Agency (IAE) or the French INSEE ("*Institut National des Statistiques et des Études Économiques*". It mainly allows to upload long-term series. The annual energy statistics summarize the consumption of the different energies. This database presents the annual series in units (per kWh for gas or electricity). All statistics can be downloaded free of charge and reused with any license or payment of royalties, provided the acknowledgment of the source.

More details about Pégase database are available on `http://www.statistiques.developpement-durable.gouv.fr/donnees-ligne/r/pegase.html`

F.2   EU-SILC database

The "*EU Statistics on Income and Living Conditions (EU-SILC)*" is a database which covers 4 topics: people at risk of poverty or social exclusion, income distribution and monetary poverty, living conditions and material deprivation. It deals with several european countries.

"*EU Statistics on Income and Living Conditions (EU-SILC) methodology is a Eurostat online publication describing the methodological and practical framework for the computation and production of the European Union's (EU) statistics on income and living conditions published in Eurostat's dissemination database. It provides information on the calculation of the published datasets, along with information on their quality and methodological limitations*".

More details are available at: `http://ec.europa.eu/eurostat/statistics-explained/index.php/EU_statistics_on_income_and_living_conditions_(EU-SILC)_methodology`.

F.3   PHÉBUS database

PHÉBUS survey ("*Performance de l'Habitat, Équipements, Besoins et Usages de l'énergie*") was conducted from April to October 2013 by the ministry of ecology, sustainable development and energy ("*Ministère de l'Écologie, du Développement durable et de l'Énergie*" (MEDDE)), the general commission for sustainable development ("*Commissariat Général au Développement Durable*" (CGDD)), and the service of observation and statistics ("*Service de l'observation et des statistiques*" (SOeS)). It proposes a set of statistics dealing with housing performance, equipment, needs and uses of energy. In particular, the survey is divided into two parts: 1/-a face-to-face interview with the occupants of the home about their energy consumption, expenditures, and attitudes and 2/-an energy performance diagnosis of the dwelling.

One major innovative contribution of PHÉBUS is that it allows to study fuel poverty since it contains information on both household, *i.e.* disposable income information as well as energy expenditures and attitudes toward energy consumption, and dwelling characteristics. In particular, PHÉBUS allows to deeply study households' energy consumption. Indeed, detailed information is provided on energy consumption according to each type of fuel and energy tariff. We exactly know for each housing unit the kind of tariff subscription and the subscribed power which are,

both, function of the fuel used for the heating system (share of electricity and gas in total energy expenditures according to end-uses) and the surface of the dwelling.

G   Methodology used to calculate energy prices

EU-SILC database does not provide data on energy prices. Only information on electricity and gas expenditures are available. As a consequence, in order to estimate the effect of energy prices fluctuations on household energy expenditures, we need to complete our database and calculate energy prices per household. At this end, we consider two crucial points. First, the type of energy tariffs in France depends on the power needed for space and water heating, appliances, lighting and cooking, etc. This power itself depends on the structure of the energy mix in the dwelling (share of gas and electricity) and the size of the dwelling (surface area). For instance, electricity tariff is not the same for a dwelling using gas for heating and a dwelling using electricity for a given surface area. Such information on type of tariffs is available in PHÉBUS database. Second, we need to associate to each dwelling (household) a type of energy tariff (divided between the price of the subscription and the unit cost of kWh) which depends on its surface and its energy mix. For each household, we should determine a type of electricity tariff and a type of gas tariff. From a practical point of view, to feed the EU-SILC database with energy prices, we proceed by following 3 steps:

— first, we split the EU-SILC database into categories according to the surface of the dwelling (10 classes), the share of electricity expenditures (10 classes from 0% to 100%) and the share of gas expenditures (10 classes from 0% to 100%),

— second, we split the PHÉBUS database into the same categories. Since for each category of household, a type of tariff for electricity and gas is given in PHÉBUS database, we incorporate this information (tariffs) into the EU-SILC database. This step lets us attribute for each housing unit in EU-SILC database a type of electricity and gas tariff.

— finally, we use information provided by the PÉGASE database to assign to each type of energy tariff in the EU-SILC an energy price covering subscription fees and consumption.

The merging process is summarized in the figure G.1 below. Otherwise, table G.1 displays official electricity and gas tariffs and associated prices that we have used in our merging process.
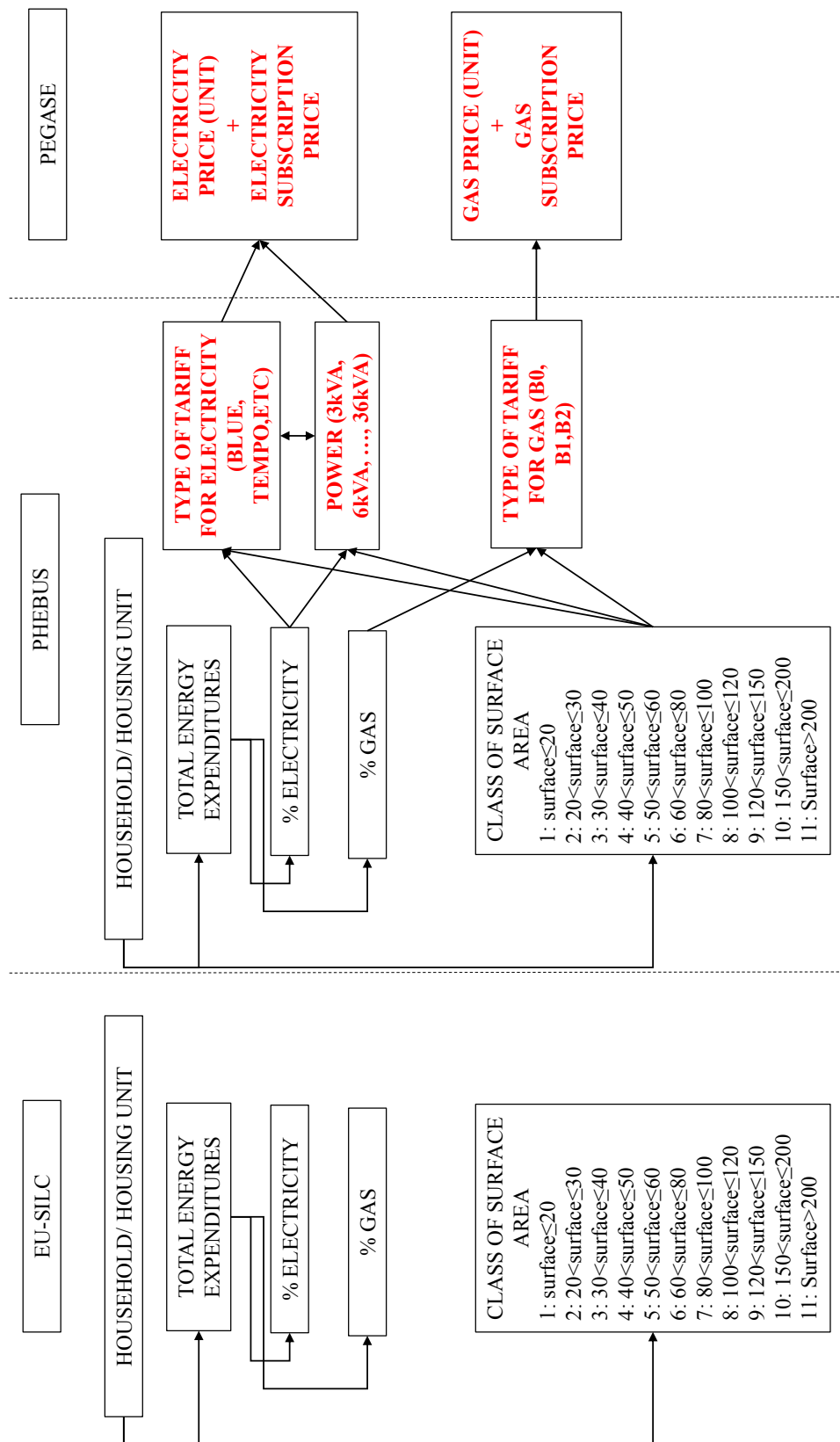
Figure G.1. Summary of the merging process permitting to calculate energy prices. Source: authors elaboration.

Table G.1 – Energy tariffs (2006-2013) used to calculate the energy prices

	2006	2007	2008	2009	2010	2011	2012	2013
			Electricity tariffs					
Electricity, blue tariff, base option in € (tax included)								
Annual subscription cost 3 kVA	23,89798	24,11667	24,51333	42,33033	68,02905	64,94606	67,40325	62,84999
Annual subscription cost 6 kVA	60,83597	61,34167	62,26667	68,86288	79,60103	77,45169	80,36592	84,32679
Annual subscription cost 9 kVA	120,05802	121,10083	122,80917	112,76375	96,8435	90,3377	93,76717	103,98908
Annual subscription cost 12 kVA	172,32332	173,72167	176,01917	173,81625	161,82429	142,84527	148,13392	162,46268
Annual subscription cost 15 kVA	224,58528	226,34083	229,235	220,40483	192,97068	164,85725	171,04758	187,11733
Annual subscription cost 18 kVA	276,85058	278,96167	282,445	266,99758	238,81541	219,2238	227,44092	233,87278
Price for 100 kWh (power 3 kVA)	14,98	15,17667	15,395	15,11583	16,5125	17,02237	17,7994	18,38731
Price for 100 kWh (power 6 kVA)	14,22083	14,3925	14,60083	15,0075	15,56917	16,23193	16,9816	18,1521
Electricity, blue tariff, peak hours tariff in € (tax included)								
Annual subscription cost 6 kVA	105,4267	106,3325	107,84667	106,18071	101,25412	93,13223	96,59658	97,36873
Annual subscription cost 9 kVA	189,26538	190,7625	193,51667	178,57946	140,10612	111,76704	115,91475	122,31733
Annual subscription cost 12 kVA	273,10902	275,19417	279,1225	261,51175	220,06033	189,49559	196,56458	205,38349
Annual subscription cost 15 kVA	356,94765	359,62417	364,73833	337,03417	270,04042	223,04773	231,32342	240,47863
Annual subscription cost 18 kVA	440,79128	444,06	450,35	412,55075	318,97905	254,38013	263,81675	273,0081
Annual subscription cost 24 kVA	737,63455	743,4875	754,14917	690,63436	580,88412	529,87303	549,78758	560,82791
Annual subscription cost 30 kVA	1034,47698	1042,915	1057,94833	963,22013	766,4663	652,50116	677,02358	679,4427
Annual subscription cost 36 kVA	1331,32437	1342,3525	1361,75333	1235,80483	942,68368	754,42164	782,73067	784,14173
100 kWh peak-hours	10,64083	10,78583	10,9375	11,26	11,8775	12,91385	13,54292	14,55315
100 kWh peak-off	6,48167	6,56917	6,66	6,98417	7,54833	8,76965	9,23933	10,00336
Price for 100 kWh (power 6 kVA)	12,10417	12,25417	12,43	12,7075	13,1625	14,03546	14,70435	15,64518
Price for 100 kWh (power 9 kVA)	11,775	11,92417	12,09583	12,2175	12,30417	13,02266	13,65389	14,66745
Price for 100 kWh (power 12 kVA)	11,14083	11,28	11,44167	11,62833	11,90583	12,77758	13,39973	14,38309
Electricity, blue tariff, tempo option in € (tax included)								
Annual subscription cost 9 kVA	162,63282	164,06417	166,5075	145,57613	115,00574	109,04157	113,022	120,17613
Annual subscription cost 12 kVA	222,63263	224,57167	227,93833	222,68442	214,26835	203,35865	210,90942	212,62099
Annual subscription cost 30 kVA	409,58732	413,17417	419,31083	444,52454	479,03303	456,64613	473,54025	546,94455
Annual subscription cost 36 kVA	550,46912	555,39417	563,89417	577,58796	594,67214	566,42158	587,43975	674,79218
100 kWh blue days and peak-off	4,485	4,53667	4,59333	5,02333	5,62496	6,8142	7,2111	7,92828
100 kWh blue days and peak-hours	5,56333	5,63083	5,70583	6,295	7,11058	8,20155	8,65528	9,48507
100 kWh white days and peak-off	9,1325	9,2575	9,38083	9,18	8,86254	9,8401	10,35061	11,22325
100 kWh white days and peak-hour	10,82083	10,97	11,1275	11,05417	10,90929	11,7537	12,33594	13,3671

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Table G.1 – Complete the previous page

	2006	2007	2008	2009	2010	2011	2012	2013
100 kWh red days and peak-off	16,9325	17,16917	17,42167	17,76167	18,17804	18,5589	19,40033	20,73046
100 kWh red days and peak-hour	47,34917	48,02667	48,73	49,69417	50,88158	49,16455	51,17409	54,34604

Electricity, market tariff, in € (tax included)

	2006	2007	2008	2009	2010	2011	2012	2013
All tariff		11,4164	11,23334	11,48405	12,44275	13,41974	13,82434	14,67013
Tariff DA		23,22329	23,03031	22,62814	23,33377	24,45679	25,13133	28,20565
Tariff DB		14,2505	14,09432	14,0427	15,0075	15,8404	16,3847	17,74836
Tariff DC		12,17538	12,07868	12,06498	13,12644	14,02566	14,45913	15,5346
Tariff DD		10,67828	10,55988	10,92719	11,83248	12,84391	13,2134	14,30701
Tariff DE		9,95671	10,15655	10,48225	11,48295	12,54369	12,91665	13,01667

Gas tariffs

Natural Gas, price in € (tax included)

	2006	2007	2008	2009	2010	2011	2012	2013
Annual subscription cost - base tariff	25,32	25,32	29,99365	34,5618	39,81045	43,8933	46,92645	52,961
Annual subscription cost - tariff B0	35,95	35,9544	41,9046	47,88645	53,35665	58,0092	61,97075	66,6338
Annual subscription cost - tariff B1	125,21	125,2074	141,581	160,149	175,41225	185,18415	195,4546	209,10455
Annual subscription cost -tariff B2I	187,62	187,62	194,37333	171,5446	175,41225	185,18415	195,4546	209,10455
100 kWh PCS - base tariff	7,11333	7,1999	8,18655	7,96583	8,46893	9,3988	9,96987	10,36132
100 kWh - tariff B0	5,90333	5,992	6,85797	6,8117	7,2669	8,0742	8,51871	8,78259
100 kWh- tariff B1	4,22	4,3056	4,86664	4,61108	4,89583	5,58353	5,86163	5,88729
100 kWh - tariff B2I	4,05667	4,1382	4,78892	4,6081	4,89583	5,58353	5,86163	5,88729
Price for 100 kWh tariff B0	8,27333	8,3753	9,62172	9,85603	10,62315	11,74238	12,42551	12,94149
Price for 100 kWh tariff B1	5,29	5,3821	6,08373	5,88843	6,27773	7,08853	7,44654	7,54033
Price for 100 kWh tariff B2I	5,10667	5,1955	5,94003	5,66641	5,99843	6,79365	7,13536	7,20735

H   Preliminary data examination: descriptive statistics

By comparing results of descriptive statistics in tables H.1 and H.2 we find that in general whatever the measure of fuel poverty, *i.e.* 10% or LIHC indicator, fuel poor households live in older dwellings, *i.e.* 28 years compared with 20 years on average, with a bad exposure (dark dwelling) and difficulties to maintain an appropriated indoor level of warmth. These housing units are also suffering from bad insulation and the presence of leaks in the roof. Therefore, fuel poor households face not only higher energy expenditures but also low income level since their income is twice as low as the one of non fuel poor households.

Table H.1 – Main descriptive statistics relative to the whole sample

Variables	mean	sd	min	max
Energy expenditures (m^2)	15.05	8.728	0.0204	192.6
Energy prices (kWh/€)	0.128	0.0213	0.0709	0.216
Disposable income (*cu*)	25,878	22,634	180	576,46
Number of persons	2.368	1.230	1	5
Type of housing tenure	0.655	0.475	0	1
Financial ability to maintain a convenient level of warmth	0.932	0.252	0	1
Length of dwelling tenure	20.97	14.78	0	92
Roof leaks, walls, floors or foundations	0.120	0.325	0	1
Exposure and darkness	0.0770	0.267	0	1
0wnership of central or electric heating system	0.951	0.217	0	1
Climate area=*"Bassin Parisien"*- Ref	0.144	0.351	0	1
Climate area=*"Bassin Parisien"*	0.201	0.401	0	1
Climate area=West	0.156	0.363	0	1
Climate area=South-West	0.110	0.313	0	1
Climate area=Center-East	0.109	0.312	0	1
Climate area=Mediterranean	0.0957	0.294	0	1
Number of time periods	6	6	6	6
Number of households	827	827	827	827
Number of observations	4,962	4,962	4,962	4,962

Table H.2 – Main descriptive statistics relative to exogenously determined groups of fuel poor households

| | 10% definition | | | | | | LIHC (m^2) definition | | | | | |
| | Poor | | Not poor | | t-test | | Poor | | Not poor | | t-test | |
	Mean	Std dev.	Mean	Std dev.	t	Pr(|T| > |t|)	Mean	Std dev.	Mean	Std dev.	t	Pr(|T| > |t|)
Energy expenditures (m^2)	26,076	14,533	14,158	7,395	-27,107	0,000	23,578	12,719	14,351	7,923	-20,496	0,000
Energy prices (kWh/€)	0,138	0,025	0,127	0,021	-9,326	0,000	0,135	0,025	0,128	0,021	-6,956	0,000
Disposable income (cu)	13841,640	6395,395	26850,440	23189,360	10,771	0,000	13725,040	4259,650	26871,320	23230,120	10,943	0,000
Number of persons	1,779	1,053	2,416	1,231	9,682	0,000	1,587	0,789	2,432	1,237	13,014	0,000
Type of housing tenure	0,717	0,451	0,650	0,477	-2,605	0,009	0,707	0,456	0,651	0,477	-2,182	0,029
Financial ability to maintain a convenient level of warmth	0,879	0,327	0,936	0,244	4,233	0,000	0,867	0,340	0,937	0,243	5,227	0,000
Length of dwelling tenure	28,315	18,345	20,374	14,287	-10,058	0,000	29,947	18,473	20,233	14,185	-12,428	0,000
Roof leaks, walls, floors or foundations	0,186	0,390	0,114	0,318	-4,094	0,000	0,187	0,390	0,114	0,318	-4,161	0,000
Exposure and darkness	0,105	0,307	0,075	0,263	-2,114	0,035	0,099	0,299	0,075	0,264	-1,638	0,101
Ownership of central or electric heating system	0,938	0,241	0,952	0,215	1,166	0,244	0,915	0,280	0,954	0,210	3,346	0,001
Climate area="Bassin Parisien" - Ref	0,046	0,209	0,152	0,359	5,612	0,000	0,037	0,190	0,153	0,360	6,137	0,000
Climate area="Bassin Parisien"	0,194	0,396	0,202	0,401	0,353	0,724	0,221	0,416	0,199	0,400	-1,015	0,310
Climate area=North	0,140	0,348	0,076	0,264	-4,408	0,000	0,141	0,349	0,075	0,264	-4,521	0,000
Climate area=East	0,143	0,350	0,093	0,290	-3,144	0,002	0,136	0,343	0,093	0,291	-2,693	0,007
Climate area=West	0,132	0,339	0,158	0,365	1,330	0,184	0,149	0,357	0,157	0,364	0,380	0,704
Climate area=South-West	0,129	0,336	0,108	0,311	-1,238	0,216	0,115	0,319	0,110	0,312	-0,298	0,766
Climate area=Center-East	0,111	0,314	0,109	0,312	-0,082	0,934	0,109	0,312	0,109	0,312	-0,007	0,995
Climate area=Mediterranean	0,100	0,300	0,095	0,294	-0,272	0,785	0,083	0,276	0,097	0,296	0,894	0,371

I Brief literature review on price and income elasticities in the residential energy demand sector

Table I.1 – Brief literature review on price and income elasticities in the residential energy demand sector

| Reference	Country	Price elasticity	Income elasticity
Parti and Parti (1980)	UK	Electricity: -0.758	0.15
		Gas: -0.311	0.15
Dubin and McFadden (1984)	US	Electricity: -0.26	0.02
Baker et al. (1989)	UK	Electricity	-0.758
		Gas	-0.311
Nesbakken (1999)	Norway	All energies: -0.50	0.01
Vaage (2000)	Norway	Heating energy	-1.24
Nesbakken (2001)	Norway	All energies: -0.21	0.06
Halvorsen and Larsen (2001)	Norway	Short-run: -0.43; Long-run: -0.44	—
Leth-Petersen and Togeby (2001)	Denmark	Oil: -0.08	
		District heating: -0.02	
Labandeira et al. (2006)	Spain	Electricity: -0.79	—
		Gas: -0.04	—
Rehdanz (2007)	Germany	Oil: [-2.03 ; -1.68]	
		gas: [-0.63 ; -0.44]	
Killian (2008)	US	All energies: -0.45	—
Meier and Rehdanz (2010)	Germany	Oil: -0.4	—
		Gas: [-0.34 ; -0.36]	—
Rich and Salmon (2017)	France	All energies: -0.485	0.0295
Filippini et al. (2014)	EU	All energies: [-0.26 ; -0.19]	—
Miller and Alberini (2016)	US	All energies: [-0.56 ; -0.76]	—
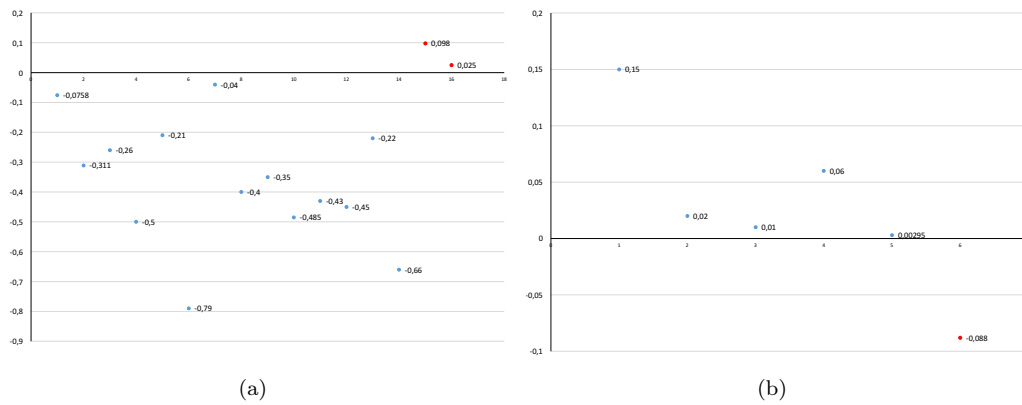
Figure I.1. (a) Comparative plot of price elasticities (authors estimates are in red, literature estimates are in black), (b) Comparative plot of income elasticities (authors estimates are in red, literature estimates are in black). Source: authors elaboration based on table I.1 above.

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