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# On the power of indicators: how the choice of the fuel poverty measure affects the identification of the target population

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**Abstract**

We propose a critical analysis of fuel poverty indicators and demonstrate that choosing a given fuel poverty indicator and, in particular, its threshold level, is central to the identification of the fuel-poor population.

First, we conducted an inter-indicator analysis to show how profiles of fuel-poor households vary depending on the indicator selected. More specifically, after identifying groups of affected households using a set of objective and subjective measures, we designed a multidimensional approach based on a combination of complementary methods, namely, a multiple correspondence analysis and a hierarchical and partitioning clustering analysis to analyse their characteristics. Through this framework, we highlight the difficulty of identifying a "*typical profile*" for fuel-poor households because of the significant variability in their characteristics and we show that the composition of the population depends on the choice of the indicator.

Second, we applied an intra-indicator analysis using two objective expenditure-based indicators with thresholds. In particular, we conducted a sensitivity analysis based on a logit model including variables describing household and dwelling characteristics. We show that the profiles of fuel-poor households as well as the drivers of fuel poverty vary considerably with the chosen threshold level.

Given these findings, we stress the need to review how we currently rely on conventional fuel poverty indicators to identify affected groups and give some recommendations.

Keywords

Fuel poverty, Groups identification, Measures dismantling, Multidimensional analysis, Sensitivity analysis.

*JEL* classification

$C_{20}$; $Q_{40}$; $Q_{48}$

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# 1 Introduction

Fuel poverty refers to a multidimensional concept that considers three main factors namely the household financial situation, dwelling characteristics, *i.e.* energy efficiency, and energy prices (EPEE (2006), Devalière (2007), Palmer et al. (2008), Blavier et al. (2011)). A household is fuel poor when it lives in an energy inefficient dwelling and is unable to heat its home at an appropriate standard level of warmth [3] due to insufficient financial resources.

Despite the spread of fuel poverty in Europe and its recognition by governments as a social, public health and environmental policy issue in an context of ever-increasing energy prices, the European Union (EU) has not yet adopted a common definition of fuel poverty nor common indicators to measure it [4]. The UK government was the first to acknowledge the phenomenon and set up measures to fight it. In fact, the fuel poverty concept was born in the UK in the 1970s under the leadership of activist organisations that called the issue to the attention of authorities and the general population in light of the winter mortality induced by the steady rise in energy prices preventing some households from heating their dwellings at an appropriate standard level of warmth (Dutreix et al. (2014), ONPE (2014), ONPE (2015)). Two decades later, Boardman (1991) based on an earlier contribution by Isherwood and Hancock (1979) defined an indicator that has since been used in the 2001 UK Fuel Poverty Strategy to measure fuel poverty [5].

In France, the official definition of fuel poverty was published in by the National Environmental Commitment Act (no. 2010-788 of 12 July 2010, "Loi Grenelle 2") amending the Housing Rights Act (no. 90-449 of 31 May 31 1990, "Loi Besson") [6]. According to this definition, a fuel-poor household represents a person who has difficulties inside her/her dwelling to have access to energy to satisfy his/her basic needs due to insufficient financial resources or inadequate dwelling characteristics *i.e.* energy inefficiency, presence of dampness and rot. Although it provided an official general framework for defining the fuel poor, the French definition of fuel poverty remains impractical. In particular, it does not establish any clear-cut operational criteria to ensure the reliable identification of fuel-poor households and, therefore, appropriate implementation of policies to fight fuel poverty (Host et al., 2014). Recently, inspired by developments in the UK, the French national observatory of fuel poverty ("*Observatoire National de la Pauvreté Énergétique*"(ONPE)) uses various objective and subjective indicators to measure the magnitude of fuel poverty ((ONPE, 2014), (ONPE, 2015)).

Along the same lines, with the goal of combatting the problem, the French government passed the Energy Transition for Green Growth Act of 17 August 2015, which contains a social component calling for the prevention of fuel poverty by implementing short- and long-term policies. In

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

4. However, the European Fuel Poverty and Energy Efficiency (EPEE) project conducted between 2006 and 2009 used, a descriptive approach to analyse fuel poverty in some European countries, *i.e.* Belgium, France, Italy, Spain and the United Kingdom. It was based on three criteria: 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).

5. 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))*".

6. La "Loi Besson" no. 90-449 of 31 May 1990 stipulates that anyone encountering difficulties, particularly due to insufficient financial resources or inadequate living conditions, can benefit from the support of the community, according to the rules stipulate in the Act, to have access to decent and independent housing ensuring water, energy and telephone access - Translated from French (JORF, 1990).

particular, it has set up curative measures to help fuel-poor households to pay their energy bills, *i.e.* income support, affordable fuel pricing and assistance with solvency in the case of arrears, and preventive policies that focus on the improvement of dwelling energy efficiency, *i.e.* dwelling insulation, double glazing, etc.

Prior to discussions on the effectiveness of these different policies, debates have always focused on the key issue of reliably identifying fuel-poor households and describing their profiles. Within these debates is the question of the relevance of fuel poverty indicators based on which one identify the affected population. The extent of the problem, the composition of groups, and, therefore, the implementation of suitable public policies depend strongly on the types of indicator used to identify the fuel poor and on their construction.

In addition to discussing drawbacks of conventional indicators, one recurrent question deals with the choice of the type of indicator to use to identify fuel-poor households: energy expenditure-based measures with thresholds, subjective self-reported measures or consensual social measures? In a recent study, Heindl and Schuessler (2015) showed that most energy expenditure-based measures show odd dynamic behaviour in micro-simulations, and can thus lead to misleading or opposite conclusions on population identification. Considering the same type of expenditure-based measures, Hills (2012) previously argued that their construction can make them overly sensitive to energy prices, and thus to a misidentification of the fuel-poor population. Similarly, because most expenditure-based indicators are based on the definition of energy expenditures and/or income thresholds, several criticisms based on discursive analyses have focused on the main impacts of the choice of the type of threshold on the identification process [7]. Although some authors argue for the use of an absolute threshold as in the case of the 10% indicator, others support the use of relative thresholds based on means or medians of expenditures (Moore (2012), Boardman (2012), Liddell et al. (2012)). Regardless of the type of threshold, the choice of the level to apply often lacks theoretical foundation (Boardman, 2012). For example, the 10% threshold was set by doubling the median energy expenditures based on the 1988 Family Expenditure Survey for UK households, which has not been updated since. Beyond the question of the threshold, some other criticisms focus on the choice of statistics used to build the indicators, for example the type of income, *i.e.* full income, residual income, equalised income and the type of energy expenditures, *i.e.* actual and theoretical, estimated expenditures ((Moore, 2012), Heindl (2013)). Finally, other studies have highlighted the need to fundamentally review how indicators are defined to account for the multidimensional nature of fuel poverty, which complicates the identification process. Fuel poverty cannot be reduced to a solely monetary dimension, neglecting other important related issues such as general deprivation (poverty), health, social exclusion and even environmental concerns.

The critical review of the literature on fuel poverty measures raises two important issues. First, because fuel poverty measures have neither real theoretical foundations nor reached an empirical consensus as to the identification of fuel-poor households, one can ask whether or not the use of one indicator rather than another may prevent some affected households from being targeted by public policy measures devoted to eliminating the problem? If so, what is the trade-off and how is it applied, *i.e.* type of indicator, its construction or both? Second, we simultaneously focus on the associated central question of the homogeneity of profiles of the fuel poor and how it can impact the implementation, the reliability and the relevance of public policy targeting. To deal with these two issues, in this paper, we analyse in detail the impact of the choice of indicator on the identification of fuel-poor households, in particular, on the description of their profile. Our aim is to lend empirical support to the discursive criticisms of current fuel poverty measures which

7. As far as we know, no quantitative analyses or empirical applications have been carried out in support of these criticisms.

highlight the influential trade-offs operating during the design and monitoring stages of economic policies devoted to fighting fuel poverty. By using an original French database developed to study the fuel poverty issue (in France), we demonstrate the variability in the profiles of fuel-poor households across indicators and how their threshold level is constructed. The composition of fuel-poor households, and thus their characteristics, depend on which measure is used.

The paper is structured as follows. In section 2, we critically review fuel poverty measures. We distinguish three groups of measures: objective factual measures, subjective self-reported measures and composite indices. We detail their respective advantages and drawbacks. In section 3, we analyse how profiles of fuel-poor households vary across indicators and with the indicator threshold. In particular, in subsection 3.2 we identify affected households using a set of conventional objective and subjective indicators and we propose a multidimensional qualitative approach based on a multiple correspondence analysis (MCA) and a hierarchical and partitioning clustering (HPC) method to analyse their characteristics [8]. Within this framework, we highlight the difficulty of identifying a "*typical profile*" of a fuel-poor household due to the variability in their profiles and show that the composition of the fuel-poor population depends on the choice of the indicator. In subsection 3.3, based on two objective fuel poverty measures, we conduct a sensitivity analysis using a logit model including variables describing household and dwelling characteristics to demonstrate the limits of using exogenous indicator thresholds. We find that profiles of fuel-poor households, as well as drivers of fuel poverty, vary considerably depending on the chosen threshold level. In section 4, we discuss our results and give some recommendations. Finally, in section 5, we draw some conclusions.

# 2 Critical review on fuel poverty measures

In this section, we briefly present and discuss the advantages and drawbacks of fuel poverty measures that divide the general poulation into homogeneous groups. Figure 1 and appendix A summarise the content of the section.

## 2.1 Objective factual measures

Objective factual measures of fuel poverty are based on measurable and observable criteria. We distinguish between expenditure-based measures, the restriction behaviour approach and consensual social measures.

*Expenditure-based measures*

Expenditure-based measures draw on notions from consumption economics. In particular, they take into account the amount of expenditures devoted to satisfy fuel needs with respect to the total available financial endowments. We examine here the 10% indicator, the after fuel cost poverty (AFCP) indicator and the low income high cost (LIHC) indicator.

— The 10% indicator

8. Although our goals differ, Hache et al. (2017) is, as far as we know, the only study that has used a clustering analysis based on CHAID methodology to separate French household energy consumption into several homogenous groups with regard to fuel poverty by relying on pre-identified predictors from the literature. Although that study offers a useful description of profiles of fuel-poor households, it does not overcome the criticisms that we address in this paper with regard to identification of the fuel poor.

The 10% indicator, also called the fuel poverty (FP) ratio, is calculated as follows:

$$\begin{aligned} \text{The 10\% indicator} &= \frac{\text{Theoretical fuel costs}}{\text{Equalised disposable income}} \\ &= \frac{(\text{Theoretical fuel consumption} \times \text{fuel price})}{\text{Equalised disposable income}} \end{aligned} \qquad (1)$$

A household is considered as fuel poor if he spends more than 10% of its equalised disposable income (before housing costs) for fuel supply to maintain an appropriate standard level of warmth inside its dwelling [9]. The equalised disposable income is the total income of a household, after tax and other deductions, that is available for spending or saving, divided by the number of household members converted into equalised adults, *i.e.* number of consumption units ($cu$). Household members are equalised or made equivalent by weighting each according to their age using an official equivalence scale.

The 10% indicator considers theoretical rather than actual/observed fuel costs. These costs are modelled by multiplying fuel requirements by fuel prices. These requirements are calculated based on a number of factors including primarily the size of the dwelling, the number of people who live in it, its energy efficiency level and the fuels used. In addition, theoretical fuel costs capture four areas of fuel consumption, namely space heating, water heating, lights and appliances and cooking needs (DECC, 2014). Typically, the majority of the fuel bill goes towards space heating [10]. It is generally difficult to calculate theoretical fuel costs. Therefore, an alternative widespread way to determine the 10% indicator is to use actual/observed fuel costs.

Although this indicator has the advantage of taking into account under-consumption by comparing theoretical and actual fuel consumption, it is not intended to measure whether households are spending more than 10% of their income on domestic fuel, but rather whether they would need to do so to reach an 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, when based on actual fuel costs, the 10% indicator does not take into account the restriction or deprivation practices of some households, *i.e.* under-heating with regard to heating needs, induced by high fuel costs (Dutreix et al., 2014).

Using the same criticism, Hills (2011) and Moore (2012) argue that the 10% indicator does not reliably take into account the income level, particularly in the case of households with high income. In effect, in essence, when used to determine the extent of fuel poverty, the 10% indicator 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 is proportional to their high income. More fundamentally, although the 10% indicator is applied to different national contexts, it is definitely not suitable for comparisons because it was defined in reference to a now-obsolete and country-specific threshold of energy expenditures. It represents the double of median energy expenditures determined based on the 1988 Family Expenditure Survey for UK households. Since that date, it has not been updated.

— The after fuel cost poverty (AFCP) indicator

9. *Cf.* footnote number 3 for an official definition of an appropriate level of warmth.
10. In the UK in 2013, on average, around 51% of the theoretical household bill was devoted to space heating, 34% for lighting and appliances usage, 12% for water heating and 3% for cooking (DECC, 2014).

The AFCP indicator was developed by Hills (2011). It is based on the comparison between the household equalised income and the standard threshold of 60% of equalised national income, where income is considered after subtracting housing and domestic fuel costs. According to this indicator, there is a situation of fuel poverty if:

$$\begin{aligned} \text{Equalised (Income} \ - \ \text{Housing costs} \ - \ \text{Domestic fuel costs)} \quad &< \\ 60\% \text{ Equalised (Median income} \ - \ \text{Housing costs} \ - \ \text{Domestic fuel costs)} \quad & \end{aligned} \tag{2}$$

Although it is not based on the constrained income which represents the income after subtracting all constrained expenditures that should be met before turning to fuel expenditures, such as taxes, transport, health and education, one advantage of the AFCP indicator is that it takes into account housing costs. They represent only part of the constrained expenditures, but when included in calculations, they enhance the reliability of results. Another advantage of the AFCP indicator is that it can identify the aggravating effect of fuel poverty on monetary (income) poverty. It is indeed plausible that people with already high fuel costs are pushed into monetary poverty because of high fuel costs. However, one drawback of the AFCP is that a high proportion of households with very low income will be classified as fuel poor regardless of their fuel requirements. Therefore, confusion between fuel and monetary poverty can occur (Legendre and Ricci, 2015).

— The low income high cost (LIHC) indicator

Defined by Hills (2011, 2012), the LIHC indicator considers two thresholds to identify fuel-poor households. The first is the household equalised disposal income that should be less than 60% of the equalised national median disposal income. The latter is equal to the equalised income net of housing and domestic fuel costs [11]. The second threshold defines a standard level of fuel expenditures. In particular, the household equalised fuel expenditures should be equal to or greater than the required national median fuel expenditures. Therefore, according to this approach, a household is a fuel poor if:

$$\begin{cases} \text{Equalised net income} \ \leqslant \ 60\% \text{ (Equalised median net income)} \\ \text{and} \\ \text{Equalised fuel expenditures} \ \geqslant \ \text{Required national median fuel expenditures} \end{cases} \tag{3}$$

We distinguish the LIHC ($m^2$) and ($cu$). The LIHC ($m^2$) indicator equalises fuel expenditures by dividing them by the surface area of the dwelling in square meters ($m^2$), whereas the LIHC ($cu$) indicator equalises fuel expenditures by dividing them by the number of consumption units ($cu$) of the household.
With respect to the AFCP indicator, the advantage of the LIHC indicator is that it clearly distinguishes between fuel and monetary poverty by applying two different thresholds. However, as in the case of AFCP indicator, the LIHC indicator is based on the calculation of the income net only of housing and domestic fuel costs. Moreover, it does not take into account the heat-restriction behaviour of some households.

*The restriction-behavior indicator and consensual social measures*

11. Therefore, this income threshold corresponds to the definition of the AFCP indicator.

Indicators based on restriction behaviour stands out from other expenditure-based indicators, but still belongs to the class of objective measures. Restriction-behaviour indicators are based on the calculation of the actual and the theoretical fuel consumption necessary to reach an appropriate dwelling level of warmth [12] and on the determination of the difference between them. When calculated, the theoretical fuel consumption takes into account the dwelling's energy efficiency.

In addition to quantifying restriction behaviour, this approach can also determine which households have a suitable cost analysis for performing dwelling retrofit energy investments (Charlier (2013, 2014)). The main difficulty encountered when calculating this indicator is the assessment of theoretical fuel consumption [13].

Also belonging to the group of objective factual measures and in addition to the expenditure-based and restriction-behaviour indicators, consensual social measures are also used to assess the magnitude of fuel poverty. They are based on the monetary poverty and deprivation literature, which go beyond the observations exposed in the recently developed fuel poverty literature (Townsend (1979), Callan et al. (1993), Gordon et al. (2000)). These measures stipulate that some goods and services are considered as necessary for the human being to be able to conduct a socially dignified lifestyle. They are regarded as essential attributes and are socially perceived as necessary. Therefore, according to the consensual social approach, when considering the energy context, a deprivation state with regard to basic household utility needs is considered as an indicator of fuel poverty. In other words, 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, as opposed to approaches based solely on expenditure-based indicators. The use of consensual social measures relies on the combination of several dimension of energy poverty such as cooking, lighting, communication, education, etc.

## 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 a survey. The most frequently asked questions include:

— Do you suffer from thermal discomfort?
— Have you had difficulty paying your utility bills (in the past)?
— Can you afford your energy bills?
— Are you satisfied with your heating equipment?

Several studies use subjective measures to study fuel poverty. For example, Healy (2003) considers three subjective indicators based on the questions listed above to analyse the fuel poverty in Ireland and the EU. Also, the INSEE ENL (2006) and EPEE (2006) analyses of fuel poverty are based on subjective indicators. In particular, EPEE (2006) defines fuel poverty as "*the household's difficulty, sometimes even the inability, to adequately heat its dwelling at a fair price*", and in the French dwelling survey (INSEE ENL (2006)), households are asked to answer the question "*Did you suffer from the cold for at least 24 hours in your home last winter?*". Within the same framework, Price et al. (2012), in exploring the links between objective and subjective measures of fuel poverty in UK, use a subjective self-declared measure of fuel poverty based on whether consumers

12. *cf.* footnote number [3] for a standard definition of an appropriate level of warmth.
13. Charlier (2013, 2014) 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 Energy Performance Diagnosis Act of September 2006 for existing buildings put up for sale in France (JORF, 2006).

feel able to afford their energy bills.

Since these subjective indicators are constructed on the basis of self-reported answers strongly correlated with different personal standards, results of different studies should be interpreted with caution mainly with respect to the identification of fuel-poor households. In particular, the interpretation of results may contradict those based on objective factual measures, although the introduction of self-reported measures provides valuable information in terms of identifying the fuel poor and of policy development (Price et al., 2012).

### 2.3 Composite indices

Composite indices were created as a compromise between the simplicity of one-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 and, at the same time, produce a result that condenses the information into single and easy-to-interpret metrics (Thomson and Snell, 2013). Based on a set of sub-indicators, these indices aim to associate several attributes of fuel poverty that cannot be reliably depicted in a single indicator. Several attempts have been made to construct composite indices for developed countries for which the main focus is selecting which aspects of poverty to take into account, *i.e.* energy prices, income, dwelling energy efficiency, personal judgment (Thomson and Snell (2013), Fabbri (2015), Charlier and Legendre (2016), Okushima (2017)). Although these attempts make a significant contribution, there is still a room for progress in the measurement of fuel poverty. For example, based on the more exhaustive conceptual framework of the energy poverty literature applied to developing countries, which focuses on the issue of energy access rather than thermal discomfort as in developed countries, Nussbaumer et al. (2012) propose new multidimensional indicators to measure fuel poverty.

The main drawback of composite indices is that combining variables causes some form of information reduction or loss, 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 seriously misleading when identifying the fuel poor and defining public policies.

## 3 Which households are fuel poor?

In this section, we show how difficult it is to identify fuel-poor households.

We start in subsection 3.1 by calculating fuel poverty rates, or equivalently, determining the population of fuel-poor households. Then, to show the variability in profiles, we conduct inter-indicator and an intra-indicator variability analyses. The inter-indicator variability means that profiles of fuel-poor households vary depending on the indicator that we use to identify fuel-poor population (subsection 3.2). The intra-indicator variability deals with the construction of the indicator and means that when varying the threshold level of a given indicator [14], profiles of fuel-poor households vary (subsection 3.3).

### 3.1 Data and computation of fuel poverty rates

We use data extracted from the "Phébus" database ("*Performance de l'Habitat, Équipements, Besoins et Usages de l'énergie*") which is especially devoted to the in-depth analysis of the fuel poverty issue in France. This database was compiled from April to October 2013 by the Ministry of

14. We focus here on the class of "expenditure-based measures" where most indicators are based on the definition of a threshold (*cf.* section 2).

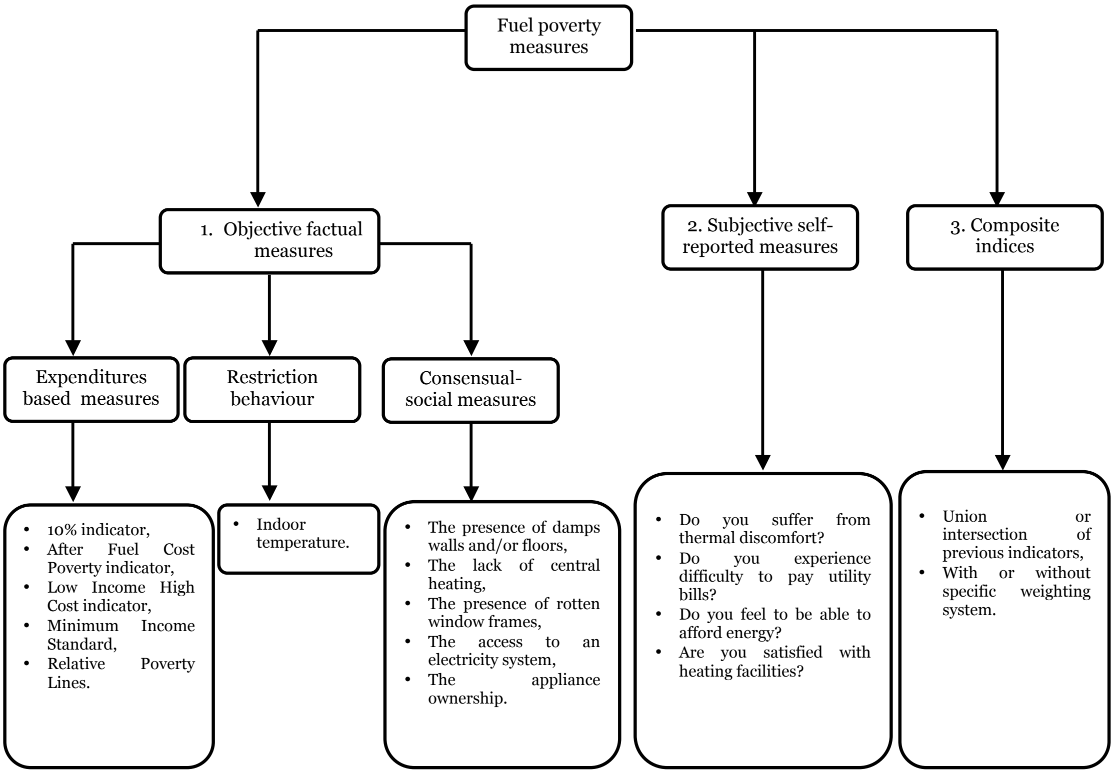



Figure 1. Summary of fuel poverty measures. Source: authors elaboration.

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 Observation and Statistics Service ("*Service de l'observation et des statistiques*" (SOeS)). It 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 efficiency diagnosis of the dwelling. In particular, "Phébus" contains information describing the household, *i.e.* the amount of energy expenditures, attitudes toward energy consumption, disposable income, age, etc., and dwelling characteristics, *i.e.* surface, type of heating system, level of energy efficiency, etc. Therefore, it permits to study households' energy consumption in detail and the associated question of fuel poverty. The "Phébus" database covers the year 2013.

We calculated fuel poverty rates for 2013 using two objective expenditure measures, *i.e.* the 10% and the LIHC ($m^2$) indicators, and one subjective measure, *i.e.* the Thermal Discomfort indicator. The latter measure relies on the answer of households to the following question "*Did you suffer from the cold in your dwelling for at least 24 hours last winter?*"[15].

In our study, we refer to the following variables used in the "Phébus" database, listed below by their acronyms, to calculate fuel poverty rates:

— Variables used to calculate fuel costs:

  — "MONTANT ELEC 2012": annual amount of electricity
  — "MONTANT GAZ 2012": annual amount of gas expenditures

15. We calculated the fuel poverty rate using the LIHC ($cu$) indicator. Because results are quite similar to those of the LIHC ($m^2$), we do not report them here to save space. They are however available upon request.

  - "MONTANT FIOUL 2012": annual amount of heating oil expenditures
  - "MONTANT GPLC 2012": annual amount of LPG (tank) expenditures
  - "MONTANT CHARBON 2012": annual amount of coal expenditures
  - "MONTANT BOIS 2012": annual amount of wood expenditures
  - "MONTANT GPLB 2012": annual amount of LPG (bottle) expenditures
  - "MONTANT PK 2012": annual amount of odourless kerosene or paraffin expenditures

- Variables used to calculate the equalised net income:

  - "REVENU DISPONIBLE 2012": disposal income
  - "EPMDR2": amount of mortgage taken out to pay for the purchase of the dwelling (for homeowners)
  - "EFAMR": amount of financial support (for homeowners - to be included when calculating housing costs)
  - "ELLD": rent (for tenants)
  - "ELAMR": amount of financial support (for tenants - to be included when calculating housing costs)
  - "UC": number of household consumption units
  - "EHST": the surface area of the dwelling.

- Variables used to detect subjective thermal discomfort (feeling cold) at home indoors and the reason for the inability to heat dwelling to a suitable level of warmth:

  - "EGCHAUF: *Did you suffer from the cold for at least 24 hours in your home last winter?*"?
  - "ETDIFF: *Have you encountered financial difficulties for paying your energy bills during the pas two years?*".

Given this list of variables, we present below how we identified fuel-poor households with each indicator. Our initial data set was composed of 5405 households.

### 3.1.1 Determination of fuel-poor households according to the 10% indicator

Based on section 2, we calculated the 10% indicator, I, using the following formula:

$$\mathrm{I} = \frac{\text{(Actual) Fuel costs}}{\text{Equalized disposable income (before housing costs)}} \tag{4}$$

- if I $\geqslant$ 10% $\Rightarrow$ the household is fuel poor.
- if I $<$ 10% $\Rightarrow$ the household is not fuel poor.

As discussed in section 2, one drawback of the 10% indicator is that it over-estimates the extent of fuel poverty within the general population by including households with a high level of income. To overcome this critisism, the ONPE (2014, 2015) studies suggest including in the calculation only those households having an income (*cu*) lower than the threshold of the third decile of income (*cu*).

Therefore, in our study, households were first sorted according to their income (*cu*) and then divided into 10 equal groups each one containing 10% of the global population to create deciles.

Then, the annual threshold of the third income ($cu$) decile was determined. Only households having an income ($cu$) level lower than this threshold were considered as fuel poor. To consolidate our calculation, we compared our threshold with national thresholds. In particular, Table 1 below presents thresholds of the third income ($cu$) decile that we calculated for 2012 in comparison with the national 2011, 2012, and 2013 thresholds calculated by the French National Institute of Statistics and Economic Studies (INSEE) (2014) [16].

Thus, a household is fuel poor if:

Table 1 – Threshold of the third decile of income ($cu$)

| Year | "Phébus" threshold | National threshold [a] |
|---|---|---|
| 2011 | — | €16 920 |
| 2012 | €16 235.20 | €16 850 |
| 2013 | — | €16 930 |

*a.* We note that these thresholds 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 fourth deciles of income.

$$\frac{\text{(Actual) Fuel costs}}{\text{Equalized disposable income}} \geqslant 10\% \tag{5}$$

and

$$\begin{aligned} \text{Equalized disposable income } (cu) \quad &= \quad \frac{\text{Disposable income}}{\text{Number of consumption unities}} \\ &< \quad \text{Threshold of the third decile of income} \end{aligned} \tag{6}$$

Our results show that 14.16% of households in our initial sample are fuel poor according the 10% indicator, *i.e.* 766 of 5405 households.

### 3.1.2 Determination of fuel-poor households according to the LIHC indicator

Based on section 2, we calculated the LIHC indicator according the following formula:

$$\begin{cases} \text{Equalised net income} \ \leqslant \ 60\% \text{ (Equalised median net income)} \\ \text{Equalised fuel expenditures} \ \geqslant \ \text{Required national median fuel expenditures} \end{cases} \tag{7}$$

Equalised fuel expenditures are calculated by dividing fuel expenditures by the number of consumption units in the case of the LIHC ($cu$) indicator and by the surface area of the dwelling in the case of the LIHC ($m^2$) indicator:

— LIHC ($cu$) indicator:

$$\text{Equalised fuel expenditures } (cu) \ = \frac{\text{Fuel expenditures}}{\text{Number of consumption units}} \tag{8}$$

— LIHC ($m^2$) indicator:

$$\text{Equalised fuel expenditures } (m^2) \ = \frac{\text{Fuel expenditures}}{\text{Surface}} \tag{9}$$

16. `https://www.insee.fr/fr/statistiques/2417897`. Accessed in July 20, 2017.

Equalised net income is calculated as follows:

$$\text{Equalised net income } (cu) = \frac{\text{Disposable income - Housing costs - Domestic fuel costs}}{\text{Number of consumption units}} \tag{10}$$

In our sample, the value of 60% of equalised median net income is equal to €12151.2 and values of the equalised median fuel expenditures in the case of LIHC ($cu$) and LIHC ($m^2$) are respectively equal to €841 and €14.64.

Our results show that 10.95% of households in our initial sample are fuel poor according the LIHC ($m^2$) indicator, *i.e.* 592 of 5405 households and 9.52% according to the LIHC ($cu$) indicator, *i.e.* 514 of 5405 households.

### 3.1.3 Determination of fuel-poor households according to the Thermal Discomfort indicator

Following the approach of ONPE (2016), a household is fuel poor according to this subjective indicator if he satisfies two conditions:

— *Condition 1*: a household declares feeling cold because of at least one of the first five reasons which are considered to be the most representative of a fuel poverty situation, namely:

1. Insufficient heating system,
2. Breakdown of heating system,
3. Poor insulation,
4. Household heating restriction due to financial burden,
5. Energy supply cut-off due to unpaid bills,
6. Improper adjustment or late start-up of the heating system,
7. Other reasons.

— *Condition 2*: a household has an income level less than or equal to the third decile.

Depending on data available in "Phébus", we consider that a household is fuel poor if he answers "Yes" to the following two questions related to *Condition 1*:

— "*Did you suffer from the cold for at least 24 hours in your home last winter?*"
— "*Have you encountered financial difficulties for paying your energy bills?*".

After that, to satisfy *Condition 2*, we selected only those households having an income level less than or equal to the third decile.

Our calculations show that 7.75%, thus, 419 of the initial 5045 households are fuel poor.

## 3.2 Inter-indicator analysis: how profiles of fuel-poor households vary across indicators

To analyse how profiles of fuel-poor households vary across indicators, we used three complementary methods. The first is a multiple correspondance analysis (MCA), which is a variation on the principal component method. The second is the hierarchical clustering (HC) method. The third is the partitional clustering method (PC).

Principal component methods include three types of analyses:

- Principal component analysis (PCA), which is suitable for analysing databases containing quantitative/continuous variables,
- Correspondence analysis (CA) which is used to handle a dataset composed of two qualitative/categorical variables,
- Multiple correspondence analysis (MCA) which is an extension of simple CA used to analyse a database containing more than two categorical variables.

The core idea common to all principal component methods is to describe a dataset ($X$with $I$ individuals and $K$ variables) using a small number ($S < K$) of uncorrelated variables that retain as much information as possible. The reduction in variables is achieved by transforming the data into a new set of continuous variables called principal components (Husson et al., 2016). One major advantage of principal component methods, in particular MCA, is that it can analyse the multidimensional character of a dataset as in the case of the fuel poverty issue. Therefore, we ran an MCA on each sample of fuel-poor households determined in the previous subsection based on the (objective) 10% and LIHC indicators and on (the subjective) Thermal Discomfort one [17].

By extension, since PCA is considered as a pre-process for clustering [18], we used our MCA results to perform hierarchical and partititional clustering (HPC). We sought to classify fuel-poor households with similar characteristics into homogeneous groups and compare the results (mainly) across indicators, although we can also analyse the variability of profiles for the same indicator. Hierarchical clustering was based on Ward's criterion. This criterion refers to Huygen's theorem which decomposes the total inertia (total variance) into between- and within-group variance. More precisely, Ward's criterion consists in aggregating two clusters to minimise the growth of within-group inertia (in other words, minimising the reduction of the between-group inertia). The within-group inertia characterises the homogeneity of a cluster. The hierarchy is represented by a hierarchical tree, *i.e.* a dendrogram, which is indexed by the increase in within-group inertia (Husson et al., 2016). This hierarchical tree can be considered as a sequence of nested partitions, ranging from one in which each individual is a cluster to one in which all the individuals belong to the same cluster. The number of clusters can then be chosen looking at the overall appearance (or the shape) of the tree, alongside the bar plot of the increase in within-group inertia, etc. These rules are often based – implicitly or not – on the growth of inertia. Different strategies are available to define clusters (partitioning). The simplest one consists in keeping the $Q$ clusters defined by the hierarchical tree. A second strategy consists in performing a K-means algorithm with the number of clusters set to $Q$. Another strategy combines the two previous ones. In our study, we used the K-means algorithm under which two conditions must be satisfied: (1) each group contains at least one point, and (2) each point belongs to exactly one group.

To select the variables to incorporate in the MCA, or equivalently, which variables best describe the fuel poverty situation, thus, a "*typical profile*" of a fuel-poor household, we reviewed the literature on fuel poverty drivers. In Appendix B, we summarise our literature review, based on which we selected the 17 most relevant variables from the "Phébus" dataset to depict fuel poverty for our MCA. In Table 2, we give these variables that describe both household and dwelling characteristics. To enhance the analysis, we also considered other variables related to the subjective

17. For the LIHC indicator, in consideration of saving space, we present below results only for LIHC ($m^2$). Results for LIHC ($cu$), which corroborate our global results, are available upon request.

18. PCA can effectively be viewed as a "noise removal" method. The first dimension extracts the essential information and the subsequent dimensions are restricted to noise. Without noise in the data, clustering is more stable.

perception of indoor cold, heating restriction behaviour, climate zone and the type of geographic setting. In Appendix C, we detail the methodological aspects of running the MCA. In particular, because MCA was designed for qualitative variables, we explain how we were able to include some quantitative variables, *i.e.* age, surface, and disposable income.

Table 2 – Variables included in the MCA (with "Phébus" codes given in parentheses)

| | Variable name and code in the "Phébus"database |
|---|---|
| Household characteristics | |
| | Sex of the household reference person (SEXE) [19] |
| | Age of the household reference person (AGEPR) |
| | Socio-economic group of the household (PCS2003) |
| | Size of the household (UC) |
| | Disposable income (REVENU DISPONIBLE 2012) |
| | Difficulty of paying energy bill (ETDIFF) |
| | Beneficiary of national social tariff for energy (ETSOC) |
| | Ownership and use of motor vehicles during the last 12 months (EVEHIC) |
| Dwelling characteristics | |
| | Type of dwelling (EHTLC) |
| | Surface of dwelling (SURFACE) |
| | Type of heating system (EKMOD) |
| | Presence of an air-conditioner (EKCLIM1) |
| | Year of dwelling construction (BATI PERIODE) |
| Other variables | |
| | Did you restrict your use of heating last winter? (ERESTRIC1) |
| | Did you suffer from the cold for at least 24 hours in your home last winter? (EGCHAUF) |
| | Climate zone (Zone climatique 1 position) |
| | Type of geographic setting (RP TAILLE UU) |

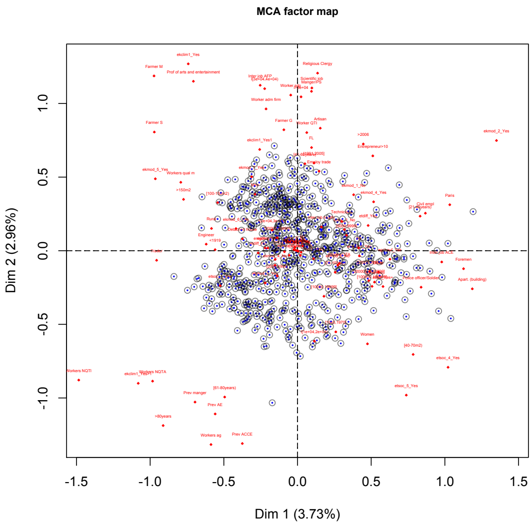
Figures 2(a) and 2(b) summarise results of the MCA for the 10% and LIHC ($m^2$) indicators, respectively (objective measures). Figure 2(c) shows the results for the Thermal Discomfort indicator (subjective measure). These figures depict clouds of individuals and their associated modalities.

Regarding the quality of graphical representation, results show that the first two dimensions/axes explain from 6.69% to 7.39% of the total variability contained in the dataset, depending on which indicator is used to identify the fuel-poor households. Such low values are typical for MCA analyses with a high number of modalities, reducing the part of variability explained by the two first dimensions. In fact, each dimension can account for just a small part of the total variability contained in the dataset (Husson et al., 2016). In our sample, we had 92 modalities. Therefore, unsurprisingly, only a small part of variability is explained by the first two dimensions of the MCA [20].

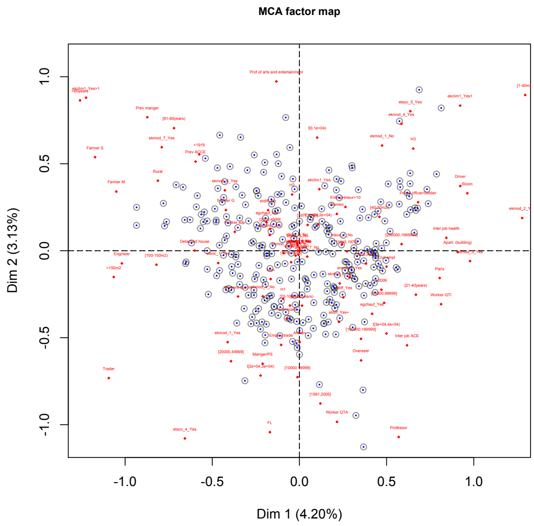
By focusing on the first two dimensions, the results of the MCA for the 10% indicator show that some similarities between households can be identified based on variables included in the MCA. Through these commun characteristics, it is possible to divide the initial sample of fuel-poor households into homogeneous groups. In particular, Figure 2(a) shows a large difference between households along the horizontal axis according to their socio-economic group, the surface area and type of their dwellings and the size of the geographic setting in which they live. In contrast to the left-hand-side group of households, representing households in a comfortable socio-economic group, *i.e.* engineers or tradesmen, and living in large rural detached houses, *i.e.* >100 $m^2$, the clusters on the right generally include urban households living in a small- to medium-size dwellings in large cities such as Paris, *i.e.* [40-70 $m^2$], declaring that they suffered from the cold during the last winter and that they frequently encounter difficulties paying their energy bills. The same figure also contrasts households along the vertical axis, which mainly transcribes age, income level

19. The code name in parentheses associated with each variable in this table refers to the code name of the variable in the "Phébus"database.

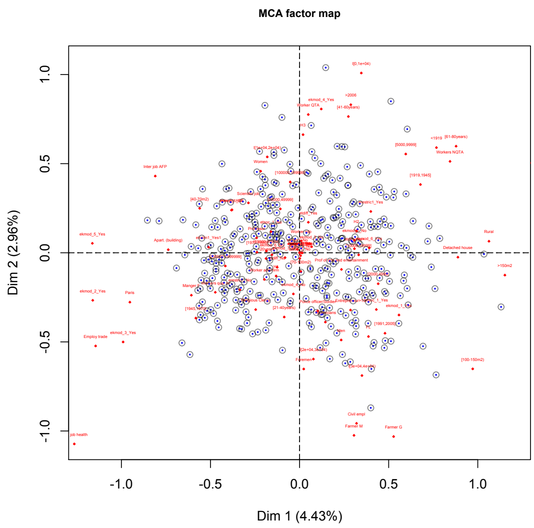
20. Histograms of eigenvalues and graphics for the third dimension and higher are available upon request.




(a)




(b)




(c)

Figure 2. (a) Cloud of individuals and modalities - 10% indicator, (b) Cloud of individuals and modalities - LIHC ($m^2$) indicator, (c) Cloud of individuals and modalities - Thermal Discomfort indicator

and the dwelling's energy efficiency (approximated by the date of dwelling construction [21]). For example, elderly households, *i.e.* >61 years, generally have a low income level and live in dwellings built before 1970.

These contrasts are corroborated by results of the MCA applied to the LIHC ($m^2$) fuel-poor population and presented in Figure 2(b). Interestingly, these results show stronger contrast between households according to their financial ability to pay their energy bill as well as their subjective perception of low indoor temperatures during the winter. The group of households having difficulty paying their energy bills and declaring having suffered from the cold lives in recently constructed dwellings, *i.e.* [1991-2005]. In addition, this group represents households having an intermediate-to-high income level relative to our sample, *i.e.* [€20,000-€40,000]. This latter result contrasts

21. The first regulation on thermal efficiency in France was introduced in 1974. Therefore, dwellings built after this date are expected to be more energy efficient.

in particular with the conventional wisdom that the fuel poor are generally people suffering from monetary poverty and living in an energy-inefficient dwelling.

Figure 2(c) shows the characteristics of fuel-poor households determined based on the subjective Thermal Discomfort indicator. It corroborates previous results and adds that it is possible to distinguish groups of fuel-poor households depending on the type of heating system, *i.e.* central heating system (boiler) *versus* independent electric heaters.

At this stage of the analysis, as expected, the MCA showed that we can identify similarities and differences between (groups of) fuel-poor households with respect to certain characteristics. Therefore, to analyse household profiles and their variability across indicators in more detail, we ran an HPC based on the MCA output. For each indicator, HPC divides the sample of fuel-poor households into sub-groups, or clusters, having the same characteristics. With this detailed description of the fuel poor by type of indicator, we compared profiles across indicators: what variables best describe the fuel poor and do their profiles vary across indicators? In other words, do identification processes vary depending on which indicator is used?

Results for the three types of indicator are shown in Figure 3. They shows that fuel-poor households are partitioned into four clusters for the 10% and LIHC ($m^2$) indicators and into three clusters for the Thermal Discomfort indicator. Households belonging to the same cluster are homogenous, but differ between clusters. Regardless of the cluster, Table 3 shows that, for each indicator, the ranking of the most represented variables (or associated modalities) is different. For example, whereas the first three variables describing the best clusters of the fuel poor determined using the 10% indicator are "Beneficiary of the national social tariff for electricity", "Age", "Socio-economic group", for the LIHC ($m^2$) indicator, they are "Age", "use of communal central heating system [22]", and "use of individual central heating system [22]". For the Thermal Discomfort indicator, the three most important variables supporting the identification process are "Age", "Type of dwelling", and "Socio-economic group". Although this indicator shares variables with the 10% indicator ("Socio-economic group" and "Age") or with the LIHC ($m^2$) indicator ("Age"), the variable "Type of dwelling" also newly supports the identification of the fuel poor according to it.

These preliminary results of the HPC analysis show that although profiles of the fuel poor are determined according to a set of common variables, or equivalently common characteristics, the importance of each variable in profile identification varies across indicators. This means that the composition of groups depends on which indicator is used. In this context, considering the eight highest ranked variables [23], Tables 4, 5, and 6 detail the composition of the fuel-poor population for the 10%, LIHC ($m^2$), and Thermal Discomfort indicators, respectively [24].

*Cross-indicator comparison of profiles of the fuel poor belongin to the most representative clusters*

To interpret our results, we consider, for each indicator, clusters of the fuel poor with the highest weight, *i.e.* cluster 2 including 40.38% of the total fuel-poor population for the 10% indicator (*cf.* Table 4), cluster 1 including 31.43% of the total fuel-poor population for the LIHC ($m^2$) indicator (*cf.* Table 5), and cluster 1 including 41.68% of the total fuel-poor population for the

22. The original variable is "The type of heating system".
23. In the interest of saving space, and because the conclusions are the same, we do not show the results for all 17 variables of the HPC analysis. They are available upon request.
24. To compare profiles across indicators, we shaded the common variables in grey and we indicated the rank of (all) variable(s) or associated levels in parentheses as already presented in Table 3. Some variables have a double ranking. For example, the variable "Type of heating system" from Table 4 is ranked 5 and 6. This means that the two modalities associated with this variable appear as the $5^{th}$ and $6^{th}$ most represented modalities. They respectively correspond to the "Yes" or "No" answers to the two following questions: "Do you lack a heating system in your dwelling?" and "Do you know what type of heating system do you have in your dwelling?"

Thermal Discomfort indicator (*cf.* Table 6). By simultaneously considering the three indicators, we also identified the most represented common variables, namely "Age", "Socio-economic group", "Type of dwelling", "Surface of dwelling", and "Type of heating system". Given these two elements, our results show that the fuel poor identified using the 10% and LIHC ($m^2$) indicators have similar characteristics with respect to the type and the surface of their dwellings, but different features with respect to their age, socio-economic group and type of heating system. In particular, the two populations of fuel poor live in large and detached houses, *i.e.* $> 100$ $m^2$. Nevertheless, the fuel poor in cluster 2 using the 10% indicator are aged from 41 to 60, are workers, and have an independent space heater(s) (or independent heating in each room), whereas those belonging to cluster 1 and determined using the LIHC ($m^2$) indicator are elderly, *i.e.* $> 61$ years, belong to a high socio-economic group, *i.e.* managers or equivalent status, and use an individual central heating systems (boiler or other type of central heating). By extension, when looking at the composition of the most important part of the fuel-poor population identified using the Thermal Discomfort indicator, *i.e.* cluster 1, results show important differences with regard to the profiles of the fuel poor using the 10% and LIHC ($m^2$) indicators. The fuel poor identified using the Thermal Discomfort indicator are very young, *i.e.* $< 20$ years, working (not attending an educational institution), living in apartments located in large cities such as Paris, and use an independent space heater(s) (independent heating in each room) or communal central heating system (communal boiler or heat pump).

In sum, comparing the most representative clusters of fuel poor population across indicators demonstrates that the differences between profiles are greater than their similarities.

*Cross-indicator comparison of the profiles of the fuel poor belongin to the less representative clusters*

As shown by Tables 4, 5, and 6, the less representative clusters are cluster 4 for the 10% indicator, cluster 4 for the LIHC ($m^2$) indicator, and cluster 3 for the Thermal Discomfort indicator. They respectively include 1.38%, 12.40%, and 22.26% of the total fuel poor population. When comparing the profiles of the fuel poor across indicators, in particular, profiles identified using the LIHC ($m^2$) indicator and those based on the Thermal Discomfort indicator [25], our results show significant differences in dwelling characteristics. Although the fuel poor identified based on the LIHC ($m^2$) indicator are young employees, *i.e.* $< 20$ years, living in small apartments, *i.e.* [1-40 $m^2$], and having a communal central heating system (communal boiler or heat pump), those identified based on the Thermal Discomfort indicator are generally older [41-60 years], employed as non-qualified workers, living in a detached house and having other type of heating system (not identified) (*Cf.* table footnote number [40]).

*Comparison of the fuel-poor profiles across classes of indicators: objective vs. subjective indicators*

In addition to the variability of profiles across indicators, our results show that these differences are heightened when switching from one class of indicators to another, *i.e.* when switching from objective indicators (10% and LIHC ($m^2$)) to subjective (Thermal Discomfort) indicator. In this context, when considering cluster 3 of the fuel-poor population identified using the 10% and LIHC

25. Because the description of dwelling characteristics of the fuel poor identified using the 10% indicator is not available, its is not judicious to compare these profiles with those identified using the LIHC ($m^2$) and Thermal Discomfort indicators. The missing information on the dwelling characteristics means that none of the variables are significantly represented in the cluster even if it can be significantly represented inside the total population of the fuel poor, *i.e.* P-value $< 2\%$ (Husson et al., 2016).

($m^2$) objective indicators, our results show striking similarities between profiles with respect to age, *i.e.* [21-40 years], the socio-economic group, *i.e.* police officer/military personnel, the type and surface of dwelling, *i.e.* detached house, and the type of heating system, *i.e.* individual all-electric heating (all-electric heating includes mounted radiators/convectors installed in every room and not inter-connected to a boiler or furnace). However, when comparing these profiles with those determined based on the subjective Thermal Discomfort indicator criteria, our results point out differences mainly with regard to the socio-economic group, *i.e.* farmer or technician *vs.* police officer/military personnel, the surface of the dwelling, *i.e.* [40-70 $m^2$] *vs.* [100-150 $m^2$], and the type of heating system, *i.e.* individual all-electric heating *vs.* individual central heating (boiler or other type of central heating).

In sum, the HPC made it possible to analyse in detail the characteristics of the fuel-poor population across indicators. It mainly highlighted that the composition of the fuel-poor population varies with the indicator. In particular, as presented in Table 3, some variables are more important than others when identifying affected groups, leading to significant profile variability across indicators. Therefore, it is still difficult to identify the fuel-poor population and to depict a "*typical profile*". Even if we succeed, this typical profile may exclude a high number of fuel-poor households, depending on the indicator selected. Some households that are fuel poor according to one indicator are not necessarily fuel poor according to another. In this context, our results show that only 259 households are fuel poor according the 10%, the LIHC ($m^2$), and the subjective Thermal Discomfort indicators simultaneously, whereas 766 households are fuel poor according to the 10% indicator, 592 according to the LIHC ($m2$), and 419 according the Thermal Discomfort indicator.

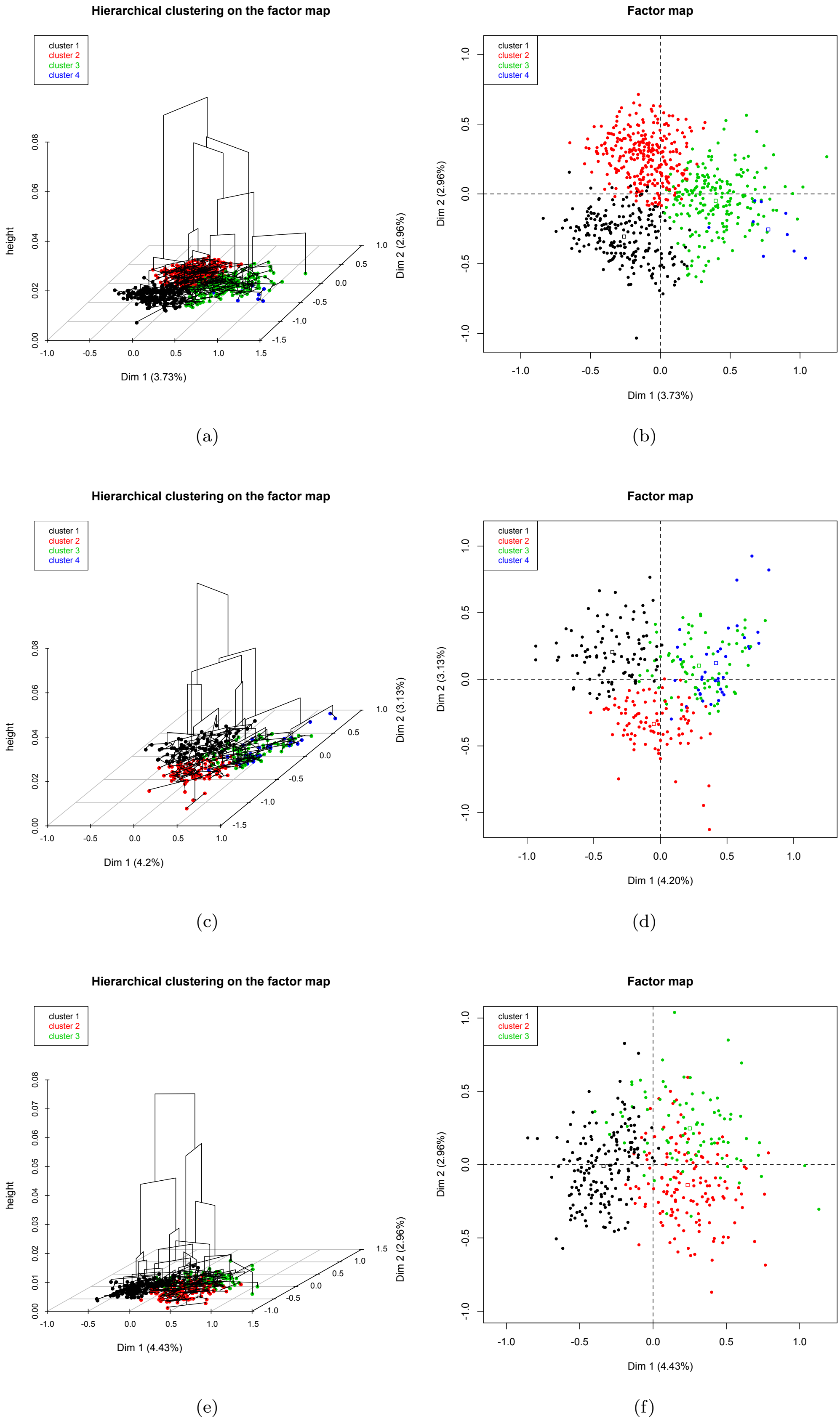



Figure 3. (a) Clusters in 3D - 10% indicator, (b) Clusters in 2D - 10% indicator, (c) Clusters in 3D - LIHC ($m^2$) indicator, (d) Clusters in 2D - LIHC ($m^2$) indicator, (e) Clusters in 3D - Thermal Discomfort indicator, (b) Clusters in 2D - Thermal Discomfort indicator

Table 3 – Ranking of the most represented variables within clusters of fuel-poor households (based on a $\chi 2$ test)

| | Fuel poverty indicator | | |
|---|---|---|---|
| | 10% | LIHC ($m^2$) | Thermal Discomfort |
| **Household characteristics** | | | |
| Sex of the household reference person (SEXE) | [9] | [20] | [19] |
| Age of the household reference person (AGEPR) | [2] | [1] | [1] |
| Socio-economic group of the household (PCS2003) | [3] | [4] | [3] |
| Size of the household (UC) | — | — | — |
| Disposable income (REVENU DISPONIBLE 2012) | [10] | [12] | [10] |
| Difficulty paying energy bill (ETDIFF) | [11] | [19] | [11] |
| Beneficiary of national social tariff for energy (ETSOC) | [1] [26], [4] [27], [15] [28], [12] [29], [22] [30] | [13] [28], [22] [30], [23] [27], | [15] [29], [21] [28], |
| Ownership and use of motor vehicles during the last 12 months (EVEHIC) | — | — | — |
| **Dwelling characteristics** | | | |
| Type of dwelling (EHTLC) | [7] | [6] | [2] |
| Surface of dwelling (EHST) | [8] | [5] | [8] |
| Type of heating system (EKMOD) | [5] [31], [6] [32], [17] [33], [18] [34], [19] [35], [21] [36] | [2] [36], [3] [34], [8] [??], [14] [35], [16] [37], [17] [31], [18] [32], [21] [38] | [4] [36], [5] [34], [12] [39], [13] [??], [14] [32], [17] [40], [18] [35] |
| Presence of an air-conditioner (EKCLIM1) | — | — | [22] |
| Year of dwelling construction (BATI PERIODE) | [16] | [11] | [7] |
| **Other variables** | | | |
| Did you restrict your use of heating last winter? (ERESTRIC1) | [20] | [10] | [9] |
| Did you suffer from the cold for at least 24 hours last winter? (EGCHAUF) | [14] | [9] | [16] |
| Climate zone (Zone climatique 1 position) | — | [15] | [20] |
| Type of geographic setting (RP TAILLE UU) | [13] | [7] | [6] |

26. "Yes" or "No" answer to the question "Do you benefit from the national social tariff for electricity?"
27. "Yes" or "No" answer to the question "Do you benefit from the national social tariff for gas?"
28. "Yes" or "No" answer to the question "Do you qualify for the national social tariff for energy?"
29. "Yes" or "No" answer to the question "Do you benefit from the national social tariff for heating oil?"
30. "Yes" or "No" answer to the question "Do you know if you qualify for the national social tariff for energy?"
31. "Yes" or "No" answer to the question "Do you have a heating system in your dwelling?"
32. "Yes" or "No" answer to the question "Do you know what type of heating system you have in your dwelling?"
33. "Yes" or "No" answer to the question "Do you have an individual all-electric heating system in your dwelling (mounted radiators/convectors installed in every room and not inter-connected to a boiler or furnace)?"
34. "Yes" or "No" answer to the question "Do you have an individual central heating system in your dwelling (boiler or other type of central heating)?"
35. "Yes" or "No" answer to the question "Do you have an independent space heater(s) in your dwelling (or independent heating equipment in each room)?"
36. "Yes" or "No" answer to the question "Do you have a communal (or collective) central heating system in your dwelling (communal boiler or heat pump)?"
37. "Yes" or "No" answer to the question "Do you have a mixed heating system in your dwelling (a specific heating system that associates a communal heating system with an individual heating system or a dual ("bi-junction") electric heating system)?"
38. "Yes" or "No" answer to the question "Do you have another type of heating system in your dwelling?"
39. "Yes" or "No" answer to the question "Do you have a district heating system in your dwelling (or a heat network)?"

Table 4 – Description of profiles of the most representative fuel-poor households in each cluster according to the 10% indicator

| | Profile description and weight of the cluster in the total sample | | | |
|---|---|---|---|---|
| | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 |
| Household characteristics | | | | |
| **[9]** Sex of the household reference person (SEXE) | — | Men (86.73%) | Women (66.02%) | Women (77.77%) |
| **[2]** Age of the household reference person (AGEPR) | [61-80] (63.42%)<br>>80 (43.05%) | [41-60] (80.95%) | [21-40] (40.66%) | [21-40] (66.67%) |
| **[3]** Socio-economic group of the household (PCS2003) | Former tradesmen, shopkeepers or business directors (21.75%) | Administrative assistants (12.24%)<br>Skilled trade worker (trade) (11.22%) | Police officer/Military personnel (19.61%)<br>Administration and sales professionals (18.66%) | Supervisor (44.45%) |
| **[10]** Disposable income (REVENU DISPONIBLE 2012) | [1e+04,2e+04] (52.77%)<br>[1e+04,2e+04] (52.77%) | [2e+04,3e+04] (42.85%)<br>[3e+04,4e+04) (29.25%) | [1e+04,2e+04] (44.01%)<br>[0,1e+04] (16.26%) | —<br>— |
| **[1-4]** Beneficiary of national social tariff for energy (ETSOC) | Do not qualify (52.77%) | Do not know (99.31%) | Do not qualify (81.39%) | Yes, for electricity (88.88%)<br>Yes, for gas (55.56%) |
| Dwelling characteristics | | | | |
| **[7]** Type of dwelling (EHTLC) | Detached house (90.27%) | Detached house (93.53%) | Detached house (37.32%) | — |
| **[8]** Surface area of dwelling (EHST) | — | [100-150$m^2$] (48.29%) | [40-70$m^2$] (51.67%) | — |
| **[5-6]** Type of heating system (EKMOD) | Individual central heating (76.30%),<br>Indep. space heaters (49.07%) | Indep. space heaters (46.25%) | Individual all-electric heating (38.27%)<br>Indep. space heaters (21.05%) | —<br>— |
| Weight of the cluster in the sample | 29.67% | 40.38% | 28.57% | 1.38% |

Table 5 – Description of profiles of the most representative fuel-poor households according to the LIHC ($m^2$) indicator

| | Profile description and weight of the cluster in the total sample | | | |
|---|---|---|---|---|
| | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 |
| Household characteristics | | | | |
| **[1]** Age of the household reference person (AGEPR) | [61-80] (47.82%)<br>>80 (17.39%) | [41-60] (64.51%) | [21-40] (48.05%) | <20 (8.10%) |
| **[4]** Socio-economic group of the household (PCS2003) | Manager (31.52%) | Shop assistants (17.20%)<br>Skilled trade workers (15.05%) | Police officer/Military personnel (32.46%)<br>Administrative and sales professionals (16.88%) | Shop assistants (24.32%)<br>Public sector assistant or worker (13.51%) |
| Dwelling characteristics | | | | |
| **[6]** Type of dwelling (EHTLC) | Detached house (92.39%) | — | Apartment (55.84%)<br>Detached house (41.55%) | Apartment (94.59%) |
| **[5]** Surface of the dwelling (EHST) | [100-150$m^2$] (35.86%) | [40-70$m^2$] (16.12%) | [40-70$m^2$] (41.55%) | [1-40$m^2$] (51.35%) |

*Cf.* next page

Table 5 – Complete the previous page

| | | | | |
|---|---|---|---|---|
| | >150$m^2$ (9.78%) | | | |
| **[2-3-8]** Type of heating system (EKMOD) | Individual (100%) | Individual central heating (90.32%)<br>Indep. heaters (24.73%) | Individual electric heating (63.63%)<br>Indep. heaters (23.37%)<br>Individual central heating (20.77%) | Communal central heating (48.64%) |
| Other variables | | | | |
| **[10]** Did you restrict your use of heating last winter? (ERESTRIC1) | No (82.60%) | — | Yes (67.53%) | No (81.08%) |
| **[9]** Did you suffer from the cold for at least 24h last winter? (EGCHAUF) | No (94.56%) | — | Yes (58.44%) | — |
| **[7]** Type of geographic setting (RP TAILLE UU) | [200000,1999999] (8.69%)<br>Paris (2.17%) | Rural (18.27%) | [200000,1999999] (32.46%) | Paris (51.35%) |
| Weight of the cluster in the sample | 31.43% | 30.76% | 25.41% | 12.40% |

Table 6 – Description of profiles of the most representative fuel-poor households in each cluster according to the Thermal Discomfort indicator

| | Profile description and weight of the cluster in the total sample | | |
|---|---|---|---|
| | Cluster 1 | Cluster 2 | Cluster 3 |
| Household characteristics | | | |
| **[1]** Age of the household reference person (AGEPR) | <20 (38.03%) | [21-40years] (56.88%) | [41-60years] (70.93%)<br>[61-80years] (18.60%) |
| **[3]** Socio-economic group of the household (PCS2003) | Administrative and sales professionals (20.85%) | Farmer G (8.45%)<br>Technicians (7.74%) | Unskilled trade or production workers (63.94%) |
| Dwelling characteristics | | | |
| **[2]** Type of dwelling (EHTLC) | Apartment (99.38%) | Detached house (78.16%) | Detached house (74.41%) |
| **[8]** Surface of dwelling (EHST) | [40-70$m^2$] (42.33%)<br>[70-100$m^2$] (38.65%) | [100-150$m^2$] (29.57%) | —<br>— |
| **[4-5]** Type of heating system (EKMOD) | Communal central heating (46.01%)<br>Indep. heaters (20.24%) | Individual central heating (66.19%)<br>Indep. heaters (35.91%) | Other (13.95%) [40] |
| **[7]** Year of dwelling construction (BATI PERIODE) | [1945,1970] (50.92%) | [1945,1970] (24.64%)<br>[1991,2006] (22.53%) | [1945,1970] (15.11%) |
| Other variables | | | |
| **[9]** Did you suffer from cold for at least 24h last winter? (ERESTRIC1) | No (72.39%) | Yes (69.71%) | — |
| **[6]** Type of geographic setting (RP TAILLE UU) | Paris (34.35%)<br>[200000,1999999] (33.12%) | Rural (33.80%) | Rural (35.80%)<br>[200000,1999999] (13.95%) |
| Weight of the cluster in the sample | 41.68% | 36.06% | 22.26% |

40. This means that households belonging to this cluster use a heating system other than individual central heating (with a boiler or other system), communal central heating (boiler), district heating, individual (built-in) electric heating, mixed (communal and individual), or independent heating equipment.

### 3.3 Intra-indicator analysis: how profiles of fuel-poor households vary depending on the construction of the indicator

In most cases, fuel poverty has been studied through the narrow use of expenditure-based measures which are – by construction – based on the definition of exogenous thresholds that lack any theoretical or empirical foundations. In this section, we analyze the drawbacks of relying on such exogenous thresholds, particularly in terms of profile variation.

As in section 3.2, we use a dataset composed of 5405 households extracted from the "Phébus" database 2013. To conduct our analysis, we used a logit specification written as follows:

$$\begin{aligned}\text{Prob}(FP = 1|X_i) &= \text{Sex} + \text{Age} + \text{Dwelling size} + \text{Household size} \\ &+ \text{Rural} + \text{Thermal discomfort} + \text{Vehicle restriction} + \text{Energy Consumption} \\ &+ \text{Post-1970 building} + \text{Unemployed} \qquad (11)\end{aligned}$$

The choice of the specification and the type of the model, *i.e.* logit, probit, cloglog, etc., do not matter here because we do not aim to identify the best econometric model to determine fuel-poor households. Instead, we focus on showing the impact of threshold variation on the identification of the fuel-poor population. In other words, we seek to show how some ranges of indicator thresholds lead to identifying some households as fuel poor and other ranges clearly exclude them.

We consider two threshold-based expenditure indicators, namely the 10% and the LIHC ($m^2$). For the 10% indicator, we modified the original exogenous threshold of 10% from 0% to 16% [41] and examine how it changes the number of households considered as fuel poor and their characteristics. We used the same methodology with the LIHC ($m^2$) indicator by modifying the standard threshold of the median of fuel expenditures, *i.e.* equalised fuel expenditures $\geqslant 1 \times$ national median expenditures, to a value ranging from 0.3 to 1.8. Since the LIHC ($m^2$) depends on a second threshold (*cf.* section 2), *i.e.* equalised net income $\geqslant 60\%$ equalised median net income, we also examined the impact of modifying the two thresholds simultaneously [42]. To save space and facilitate the presentation of the results, we report them below in graphs.

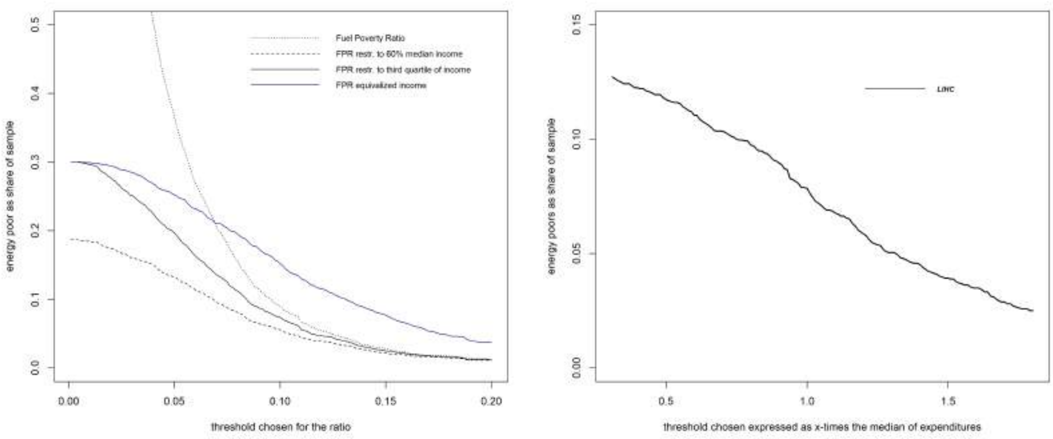
For both indicators, Figure 4(a) shows that the size of the fuel-poor population depends on the value of the threshold. For example, a 20% drop in the threshold from 10% to 8% leads to an increase in the number of fuel-poor households by a factor ranging from 28% to 74%. This result means that the elasticity of the fuel-poor population with regard to the threshold is greater than 1. The same conclusion holds when we consider the LIHC ($m^2$) indicator, as shown in Figure 4(b). For instance, when we cut the initial median threshold by 20% from 1 to 0.8, the number of fuel poor increases by 24.1%. By extension, when both thresholds of the LIHC ($m^2$) indicator are modified, we observe the same type of variation with respect to the size of the fuel-poor population.

In addition to affecting the size of fuel-poor population, changing the threshold also leads to a modification in its characteristics, or equivalently, the composition of the fuel-poor population. Therefore, it becomes more difficult to define a common profile. In particular, our results show that two effects make it difficult to describe the characteristics of the fuel poor, namely the "islands of significance effect" and the "switching signs effect".

The "islands of significance effect" relates to the fact that some variables seem to have a significant statistical impact on the probability of being fuel poor only for a narrow range of threshold values. For example, as shown by Figures 5(a) and 5(b), a standard analysis using the conventional

41. This range of values ensures that a sufficient number of observations are available for the estimation of the model, *i.e.* minimum of 50 observations for y=1 and y=0.

42. To check the quality of our results, we generated various indices of good discrimination of the model, *i.e.* AUC and Brier criteria.




(a) (b)

Figure 4. Variation in the number of fuel-poor households as a function of the indicator threshold value for (a) the 10% indicator and (b) the LIHC ($m^2$) indicator (variation in only one threshold, *i.e.* equalised fuel expenditures $\geqslant 1 \times$ national median expenditures)

10% threshold would lead to the conclusion that the variable "Sex" is significantly associated with the probability of being fuel poor, but the variable "Age" had no significant effect [43]. Conversely, the choice of another nearby range of threshold values may have led to the opposite conclusion. Similarly, as shown in Figures 5(c) and 5(d), for the LIHC ($m^2$) indicator, there was initially no significant statistical correlation between "Unemployed" status and fuel poverty and a significant correlation between "Rural" status and fuel poverty. But when we varied the threshold level, the correction became statistically significant for "Unemployed" and statistically insignificant for "Rural".

The second effect, the "switching signs effect", means that coefficients of variables included in the model change sign when the threshold level changes, *i.e.* from a significant positive effect to a significant negative effect or reciprocally.

On another side, the optimal dimension of the model, *i.e.* the number of variables to be included, obtained with stepwise selection based on our initial model (*cf.* eq. (11)) changed greatly when we modified the threshold cut-off. For the 10% indicator, after a changing the threshold from 0 to 16%, Figure 6(a) shows (at least) four important changes in the dimension of the model. The first change is identified at a cut-off of 4.9%. The second occurs for a threshold equal to 7.1%. Then, from a cut-off of 8.7% to 11.1%, we observe a transitional change where variables describing the fuel poor are subject to substantial modifications. Finally, in the last stage, the fuel-poor profiles became stable and can be described with four main variables, *i.e.* "Family size", "Rural", "Post-1970 buildings", and "Vehicle restriction". The LIHC ($m^2$) indicator displays the same behaviour. Indeed, as shown in Figures 6(b) and 6(c), fuel-poor profiles seem to be abruptly modified at a cut-off of the first threshold relative to energy expenditures, at a level slightly less than the median of energy expenditures. The optimal dimension of the model is also highly elastic to the modification of the second threshold of LIHC ($m^2$) (*cf.* Figure 6(c)). Unfortunately the threshold of 0.6 times the median income is in the middle of one of these breaks.

When we simultaneously modify of the two thresholds associated with the LIHC ($m^2$) indicator to study the statistical significance of variables [44], Figures 7(a), 7(b), and 7(c) demonstrate the

43. The value 0 is not included in the confidence intervals.

44. P-value associated with the probability of the null assumption: the coefficient of the variable is not significantly different from zero.

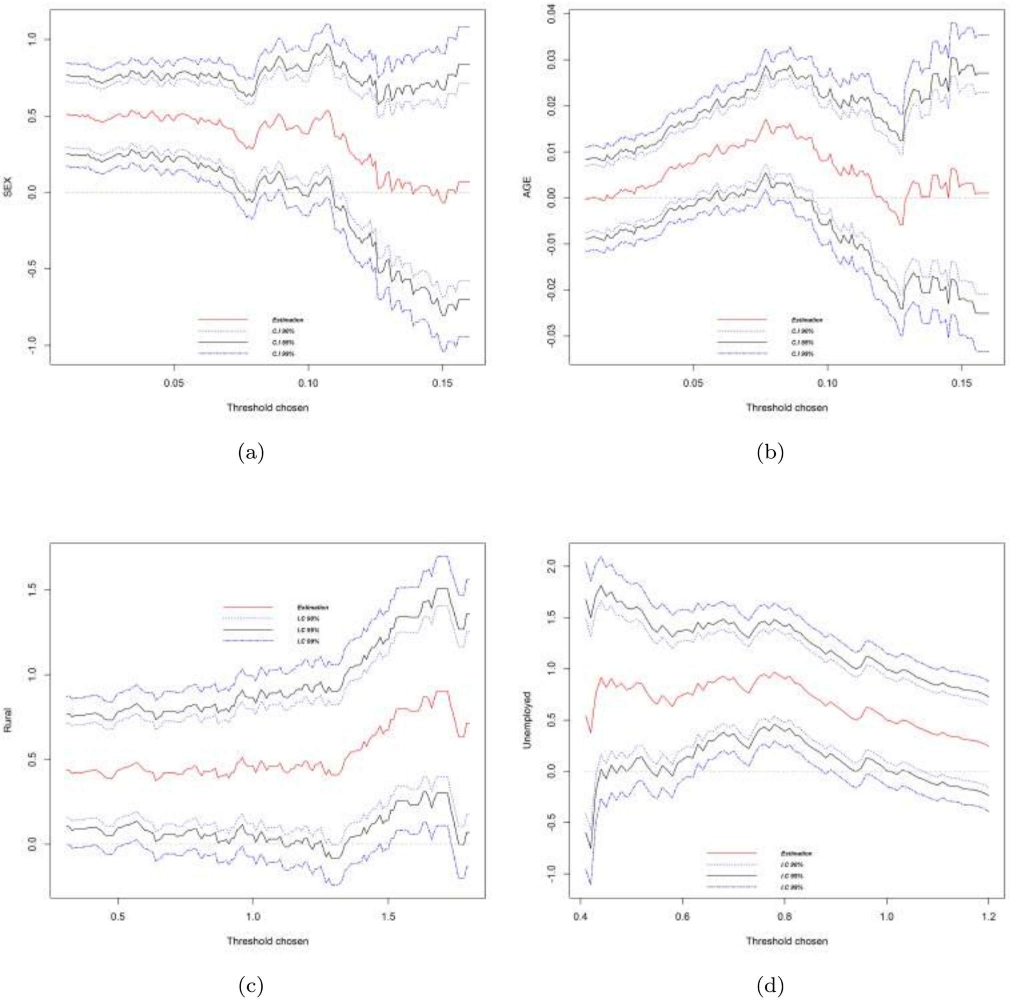
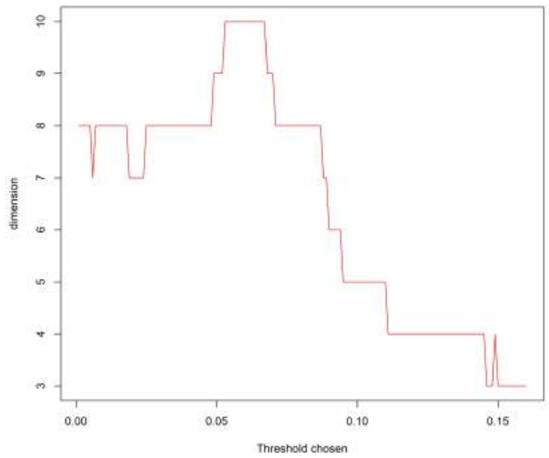
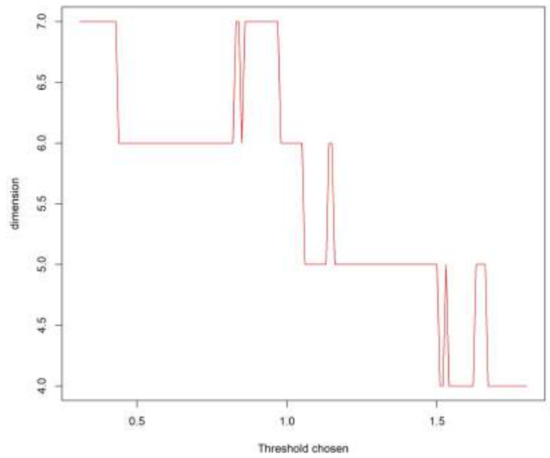



Figure 5. (a) Estimation and confidence intervals for the variable "Sex" according to different threshold levels of the 10% indicator, (b) Estimation and confidence intervals for the variable "Age" according to different threshold levels of the 10% indicator, (c) Estimation and confidence intervals for the variable "Rural" according to different threshold levels of the LIHC ($m^2$) indicator (variation of only one threshold, *i.e.* equalised fuel expenditures $\geqslant 1 \times$ national median expenditures), (d) Estimation and confidence intervals for the variable "Unemployed" according to different threshold levels of the LIHC ($m^2$) indicator (variation of only one threshold, *i.e.* equalised income $\geqslant 1 \times$ national median income)

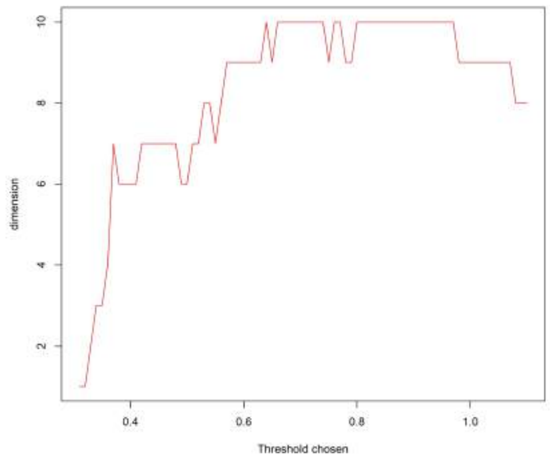
existence of statistically significant areas and statistically non-significant areas for the variables "Age", "Sex" and "Period1970". In particular, it exists flat areas and peaks for different variables and for a narrow range of threshold values which menas that there is an important instability of fuel-poor profiles.




(a)

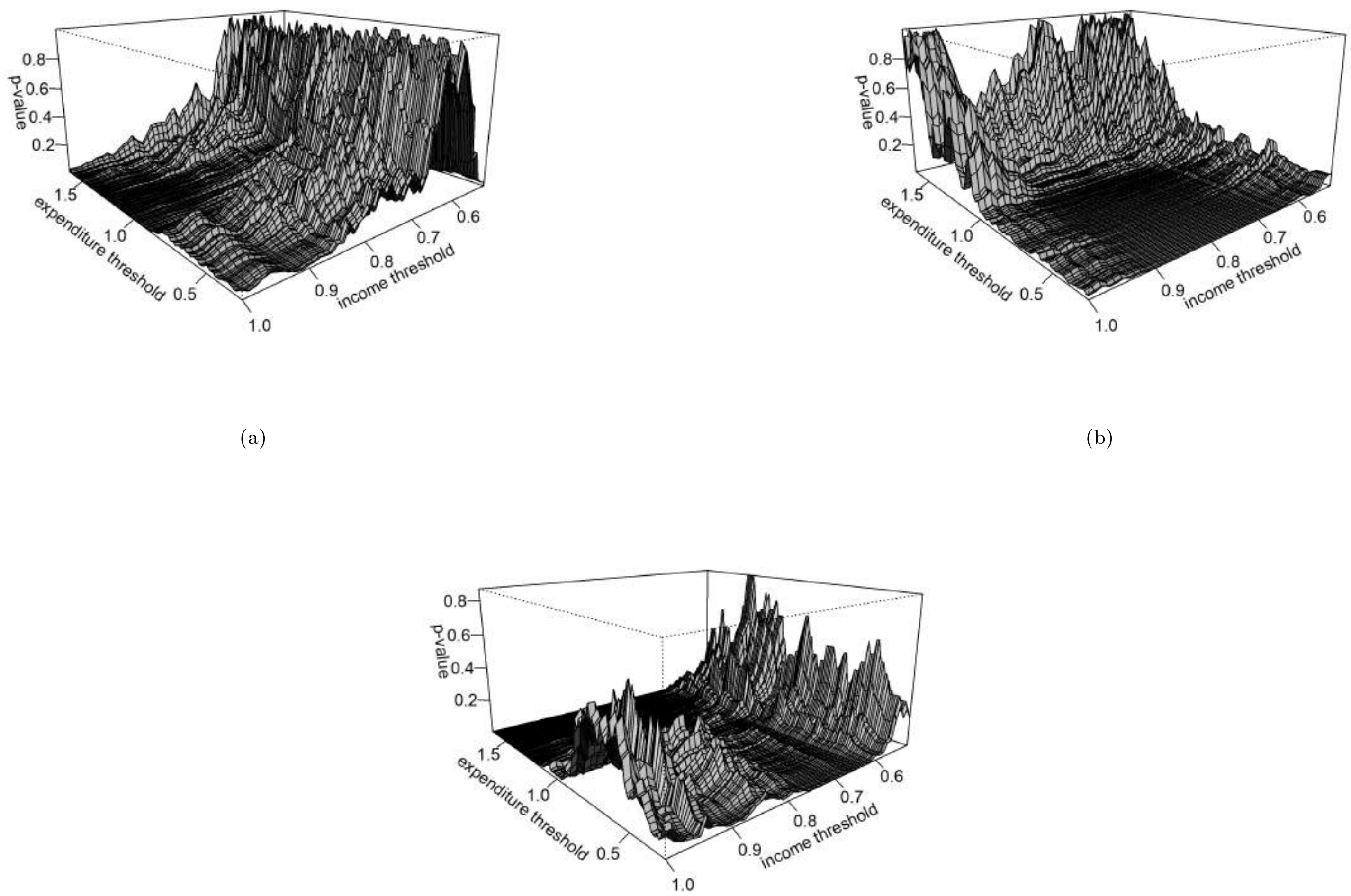



(b)




(c)

Figure 6. (a) Optimal dimension of the model according to different threshold levels of the 10% indicator, (b) Optimal dimension of the model according to different threshold levels of the LIHC ($m^2$) indicator (variation of only one threshold, *i.e.* equalised fuel expenditures $\geqslant 1 \times$ national median expenditures), (c) Optimal dimension of the model according to different threshold levels of LIHC ($m^2$) indicator (variation of only one threshold, *i.e.* equalised income $\geqslant 1 \times$ national median income)




(a) (b) (c)

Figure 7. (a) Statistical significance of the variable "Sex" in the model according to different values of the two thresholds of the LIHC ($m^2$) indicators, (b) Statistical significance of the "Age" variable in the model according to different values of the two thresholds of the LIHC ($m^2$) indicator, (c) Statistical significance of the "Period-1970" variable in the model according to different values for the two thresholds of the LIHC ($m^2$) indicator

# 4 Discussion and recommendations

Our results show how determination of the fuel-poor population depends on the choice of the fuel poverty indicator and its construction (threshold changes). Results from different indicators can be different or even conflicting, *i.e.* a person identified as fuel poor according to one indicator, may not be according to another. Although this issue has been already pointed out in the literature, it remains unresolved and even unmeasured in the majority of articles. As this issue greatly impacts, both, the determination of the magnitude of fuel poverty as well as the fuel-poor profiles, it can put into question the efficiency of identifying fuel-poor households and of policies aiming to fight fuel poverty. As long as the use of indicators with no theoretical fundementals is widespread, it opens the opportunity to use a given indicator or the threshold which favor some particular fuel-poor profiles. Now, since we highlighted the empirical importance of the issue, we argue that we need new methodologies to overcome limits of conventional indicators, thus, to measure fuel poverty in a more relevant way. Below, we give some recommendations.

*Combining conventional indicators associated with a sensitivity analysis*

When aiming to determine the fuel-poor population and analyse its profile, several types of conventional indicators can be used. For example, to measure the extent and composition of fuel poverty in France, Legendre and Ricci (2015) use three objective indicators, namely the 10%, the AFCP and the LIHC. They conclude that the share of fuel-poor households and their characteristics differ significantly depending on which indicator they use. More recently, Papada and Kaliampakos (2016) combined the objective 10% indicator with subjective indicators to mesure fuel poverty in Greece. Such way of proceeding should be generalized. In this context, in France, the French National Observatory of Fuel Poverty suggests using two approaches to measure fuel poverty (ONPE, 2016). The first one is based on a combined use of three objective expenditure indicators, *i.e.* the 10%, LIHC ($cu$) and LIHC ($m^2$) indicators, and the second is based on the subjective Thermal Discomfort indicator.

Although results of several indicators can differ, their major advantage is that they permit to analyse in detail the characteristics of fuel-poor households depending on which one is used. One complementary way to ensure results of combined conventional indicators is to associate each indicator outcome with a sensitivity analysis. The aim is to highlight how results change depending on the type of indicator or on its construction, *i.e.* threshold level. Accordingly, one can offer a reliable identification process, based on which the necessary policies targeting the elimination of fuel poverty can be implemented (Dubois, 2012).

*Alternative use of threshold-based indicators*

Another way to deal with the variation in the profiles of the fuel poor when using conventional threshold-based indicators is to use them without the thresholds. For instance, the evolution of fuel poverty can be tracked via the median of the fuel poverty ratio as well as the skewness and kurtosis of the distribution of the fuel poverty ratio. As shown in Figure 8, a shift in the median value can indicate a worsening situation whereas a shift in the symmetry of the curve can suggest an improvement with less inequality. Conversely, the skewness of the distribution can indicate a worsening situation for the most exposed fuel poor. Obviously, these indicators do not provide any head counts of the fuel-poor population and cannot quantitatively analyse the spread of the phenomenon. Nevertheless, they give an interesting complementary overview of the temporal dynamics of fuel poverty.

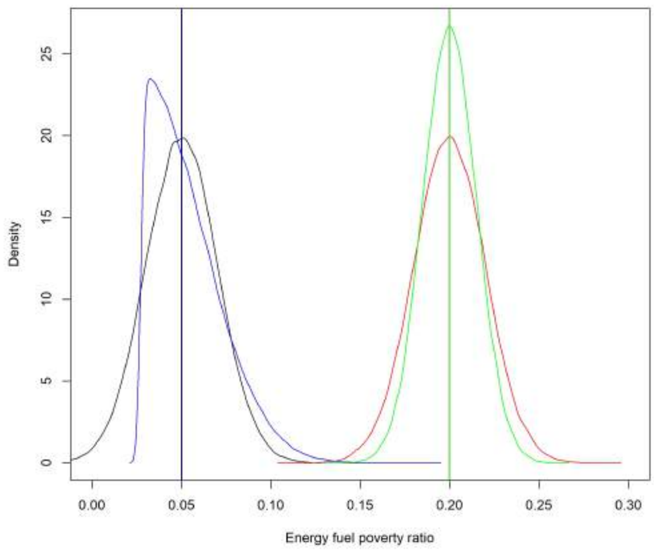



Figure 8. Alternative way of examining expenditure-based measures: evolution of the distribution of the 10% indicator Note: An arbitrary threshold is not necessarily required to analyse the dynamics of fuel poverty. Distribution shifts and asymmetry of the fuel-poor population can represent an unbiased exploratory means to consider the issue.

*Using new types of indicator*

Given that there is currently no commonly accepted approach to measure fuel poverty, several recent studies have proposed to tackle the issue by constructing new types of indicator(s). In this context, in addition to measuring fuel poverty by using the most common subjective indicators, *i.e.* arrears on utility bills, inability to keep the home adequately warm and the presence of damp walls and leaks, Papada and Kaliampakos (2016) propose new indicators focusing on health problems caused by poor heating conditions and restriction of other essential needs such as food or clothing (essential for satisfying energy needs).

In a more general framework, other studies call for the construction of indicators, so-called composite indices, taking into account the multidimensional nature of fuel poverty. In particular, Okushima (2017) constructed a multidimensional energy poverty index (MEPI) that considers three attributes of fuel poverty, namely energy costs, income and dwelling energy efficiency. Similarly, Charlier and Legendre (2016) proposed an index that takes into account household heating restrictions in addition to monetary constraints and dwelling energy efficiency.

By extension, some recent studies based on energy deprivation, a concept commonly applied to developing countries, call for the revision the conceptual framework that form the basis for the construction of the conventional indicators of fuel poverty in developed countries. In particular, they advocate the definition and the use of indicators coming from the energy capabilities framework (Sen (1992), Nussbaumer et al. (2003), Nussbaumer et al. (2012)). This framework is based on the argument that the energy demand is not for energy per se, but for the services energy use can provide such as lighting, cooking, heating and cooling. Therefore, Smith and Seward (2009) distinguish between basic and secondary capabilities [45]. Day et al. (2016) apply this capabilities approach to argue why energy is used and needed and to propose a innovative multidimensional

45. Basic capabilities are those that can be defined in broad and generic forms and are considered as the most fundamental, for example education, bodily health and social respect. Secondary capabilities are rather seen as

definition of energy poverty that integrates approaches to energy poverty from global North and South contexts. They argue that the energy capabilities framework idenfities several areas of intervention to address the problem of energy poverty, in particular, the energy poverty in the context of climate change.

# 5 Conclusion

During the last decade, the literature on fuel poverty has gained growing interest. Although it has offered and experienced many objective and subjective indicators to measure fuel poverty, it has failed to reach a consensus on the appropriate indicator to use to reliably identify affected households and implement appropriate public policies to help them to overcome the problem. Obviously, there is a trend in the use of indicators, such as for example the increasing use of the 10% indicator after its officialisation by the UK government in 2001. Similarly, the LIHC indicator has been well received since its first appearance in Hills (2011, 2012) reports. Nonetheless, several discursive criticisms related to the use of these measures have been extensively relayed in the last few years. Although most of them are valid, they clearly lack empirical support.

The aim of this paper was to fill this gap. In particular, based on critical review of the literature on fuel poverty measures, we focused on two issues. First, because fuel poverty measures have never neither real theoretical foundations nor any empirical consensus as to the identification of the fuel poor, we investigated how the use of one indicator over another can lead to the exclusion of some part of the affected population from being targeted by public policy measures devoted to fighting the problem. Further, in the case of exclusion, we sought to determine which trade-off is at work and how it is applied, *i.e.* type of indicator and/or its threshold. Second, we examined the associated crucial question of the homogeneity of the profiles of the fuel-poor popoulation and its impact on the implementation, the reliability and the relevance of public policy targeting. To address these issues, we analysed in detail the impact of the choice of indicators on the identification of the fuel-poor population, in particular, on their profile description.

Our results show that the profile of the fuel poor depends on the indicator selected and on its construction, *i.e.* threshold level in the case of expenditure measures. In particular, the inter-indicator analysis based on an MCA coupled with an HCA showed that the fuel poor computed with a given indicator pools several types of profile and that profile groups can differ across indicators. We then detailed the characteristics of some selected representative fuel-poor households. Similarly, the intra-indicator analysis shows that profiles of the fuel poor as well as the size of groups, or equivalently, the magnitude of fuel poverty has high elasticity for the level of the threshold. Based on these results, we highlight the difficulty of identifying and defining a "*typical profile*" of a fuel-poor household for the implementation of public policies.

We argue that both scholars and policy makers should be aware of the potential trade-off involved by the use of a given indicator or a given threshold. Some indicators or thresholds favour some groups of population and exclude others. We recommend employing different strategies to cope with these issues, namely the combined use of conventional indicators associated with a sensitivity analysis, the ommision of thresholds from expenditure-based indicators, and the use of new types of indicator based on a more suitable conceptual framework. Obviously, these strategies are not mutually exclusive and can be carried out together.

The difficulty of identifying the fuel-poor population reveals that there are still a lot of things to learn about fuel poverty. There are in particular three main fields of research to be explored.

component parts of materialising basic capabilities such as having access to information, using machinery and preparing food.

First, because fuel poverty is basically a dynamic phenomenon, analysing this question can help understand its duration as a function of the profiles of affected groups. Interestingly, it can also help analyse the effectiveness and enforcement of policies to combat fuel poverty. Second, there is a need to better understand the drivers of fuel poverty by distinguishing exogenous and endogenous determinants to identify the most interesting levers that can help overcome the problem. Last, but not least, studies dealing with the relationship between fuel poverty and other poverty-related concepts such as monetary poverty, heath, education and social exclusion, should be conducted. The analysis of interactions between these different issues may reveal causal and cumulative effects necessary to understand and, thus, to eliminate fuel poverty.

## Acknowledgment

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# A Brief literature review on fuel poverty measures, their advantages and their drawbacks

Table A.1 – Brief literature review on fuel poverty measures, their advantages and their drawbacks

| Main references | Definition | Advantages | Drawbacks |
|---|---|---|---|
| | | 1. Objective factual measures | |
| | | Expenditure-based measures | |
| UK Government based on Boardman (1991) | The 10% indicator:<br>— Calculation : $I = \frac{\text{Theoretical fuel costs}}{\text{Equalized income before housing costs}}$<br>— Rule:<br>— if $I \geqslant 10\% \Rightarrow$ the household is fuel poor,<br>— if $I < 10\% \Rightarrow$ the household is not fuel poor, | — The comparison between theoretical and actual energy consumption takes into account self-imposed under-heating. | — Based on an obsolete UK energy expenditures threshold going back to 1988,<br>— Based on theoretical rather than actual energy expenditures,<br>— Does not take into account heating restriction practices,<br>— Does not take into account the income level of affluent households,<br>— Does not take into account restricted expenditures. |
| Hills (2011) | The After Fuel Cost Poverty (AFCP) indicator:<br>Fuel poverty if [ Equivalised (Income − Housing costs − Domestic fuel costs) ] < [ 60% equivalised (Median income − Housing costs − Domestic fuel costs) ] | — Taking into account some constrained expenditures, *i.e.* housing costs,<br>— Identification of the aggravating effect of fuel poverty on monetary poverty. | — Plausible misleading classification of households with very low income as fuel poor regardless of their fuel needs,<br>— Possible confusion between fuel and monetary poverty. |
| Hills (2011, 2012) | The Low Income High Costs (LIHC) indicator:<br>Fuel poverty if [ Equalised net income < 60% (Equalised median net income) ] and Equalised fuel expenditures ⩾ Required national median fuel expenditures | — Definition of two thresholds that distinguish fuel from monetary poverty to ensure reliable identification of fuel-poor households. | — Not based on the constrained income,<br>— Does not take into account heating restriction behaviour practised in some households. |
| | | The restriction behaviour measure | |

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Table A.1 – Complete the previous page

| Main references | Definition | Advantages | Drawbacks |
|---|---|---|---|
| ONPES cited in Dutreix et al. (2014) and ONPE (2014) | The restriction behavior indicator:<br>Theoretical fuel consumption –<br>Actual fuel consumption | — Helps target households that have a cost analysis suitable for dwelling fuel investment. | — Theoretical energy expenditures are usually difficult to assess. |
| Consensual social measures | | | |
| Also *cf.* summary of Healy and Clinch (2002) and Nussbaumer et al. (2012) presented in the section entitled "Composite indices" in this table) | | | |
| Healy and Clinch (2002) and Nussbaumer et al. (2012) | Possibility of using different objective indicators:<br>— Presence of damp walls and/or floors,<br>— Lack of central heating,<br>— Presence of rotten window frames,<br>— Access to electricity distribution,<br>— Household appliance ownership. | — Captures multidimensional nature of fuel poverty especially when included in composite indices. | — Possible irrelevant results if used irrespective of other objective measures. |
| 2. Subjective self-reported measures | | | |
| Healy (2003), EPEE (2006), and INSEE ENL (2006) | Possibility of asking different questions:<br>— Do you suffer from thermal discomfort?<br>— Do you experience difficulty paying utility bills (in the past)?<br>— Can you afford your energy bills?<br>— Are you satisfied with your heating equipment? | — Can be supplemented with qualitative surveys/interviews to better understand the characteristics of fuel-poor households. | — Results should be interpreted with caution,<br>— Possible contrasting results compared with those of objective measures mainly with respect to the identification of fuel-poor households. |
| 3. Composite indices[46] | | | |
| Healy and Clinch (2002) | Composite weighted index based on the combination of six consensual social indicators which:<br>— Are split into two sub-groups: subjective self-reported and objective factual indicators,<br>— Pertains to household finances (fuel and utility bills), the state of the building structure (presence of damp or rot), and the dwelling's heating system. | — Associates objective and subjective criteria,<br>— Suitable for cross-country comparisons. | — Assignments of weights to each indicator incorporated in the composite indice is somewhat arbitrary,<br>— Results vary depending on the weight assigned to each indicator. |

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46. References cited in this part of the table present indices that were constructed for developed countries. Therefore, if applied to a developing country, some refinements will be necessary, especially with regard to the definition of the dimensions of poverty. In fact, when considering energy poverty in developing countries, most existing studies focus on the question of energy access, not on thermal comfort as in developed countries.

Table A.1 – Complete the previous page

| Main references | 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 12 months, the presence of a leaking roof, damp walls or rotten windows and the ability to pay to keep the home adequately warm. | — Suitable for cross-country comparisons. | — Assignments of weights to each proxy indicator is somewhat arbitrary,<br>— Results vary depending on the weight assigned to each indicator. |
| Fabbri (2015) | Composite index, the so-called Building Fuel Poverty Index (BFP), aims to assess the relationship between building energy performance, dwelling habits and fuel poverty. | — Focusing on the role of dwelling energy efficiency as a driver of fuel poverty,<br>— the index identifies subjects that can afford to pay for building energy refurbishment. | — Not generally easy to apply in countries other than Italy. |
| Okushima (2017) | Composite index, the so-called Multidimensional Energy Poverty Index (MEPI), which is composed of three attributes of energy poverty, namely energy costs, income and dwelling energy efficiency. | — Considers the multidimensional nature of energy poverty which matches the original concept of energy poverty by Boardman (1991). | — Does not take into account the subjective dimension of fuel poverty. |

# B Potential drivers of fuel poverty: summary of the literature

Table B.1 – Potential drivers of fuel poverty: summary of the literature. Based on Bennett et al. (2002), Scott et al. (2008), Healy (2003), Healy and Clinch (2004), Palmer et al. (2008), Fahmy et al. (2011), Nicolas et al. (2012), Thomson and Snell (2013), Mayer et al. (2014), Waddams Price et al. (2015), Legendre and Ricci (2015), Charlier et al. (2015), Roberts et al. (2015), Fabbri (2015), Ambrosio et al. (2015), and Hache et al. (2017).

| Drivers | Expected effect |
|---|---|
| Household characteristics | |
| -Type of household/Marital status, *i.e.* Single; Widowed; Divorced; Childless couple; Couple with child(ren); Single-parent family. | Single, widowed and divorced persons have a higher risk of being fuel poor. |
| -Size of household/Number and age of children | The presence of children increases energy needs, thus, the probability of falling into fuel poverty. |
| - Sex | Women, mainly single, with dependent children, and unemployed are usually fuel poor. |
| - Age | Elderly persons seem to be more vulnerable (higher energy needs) and more likely to fall into fuel poverty due to lower incomes. |
| - Socio-economic group | Belonging to a high socio-economic group reduces the risk of being fuel poor because it increases the probability of having a high income level. |
| - Income level, *i.e.* $>$ or $<$ poverty threshold | A high income level reduces the risk of being fuel vulnerable because its ensures the ability to afford energy [47]. |
| - Employment status | Employment ensures income, thus the ability to afford energy and reduces the risk of falling into fuel poverty. Conversely, students, unemployed workers and retirees have lower income thus higher likelihood of falling into fuel poverty. |
| - Education level | High educational level reduces the risk of being a fuel poor because it increases the probability of being employed and having a high income. |
| - Dwelling occupancy status | Homeowners are less frequently fuel poor, likely because they have higher income and ensure energy efficieny of their home. |
| - Daily occupancy of disabled and sick persons in dwelling | Disabled and sick persons have higher probability of being fuel poor due to more time spent at home, and thereby higher energy needs. |
| Dwelling attributes | |
| - Type of dwelling, *i.e.* Apartment; Detached dwelling, etc. | The fuel poverty risk increases when the household is living in a detached dwelling. |
| - Construction date | In France, the first regulations on thermal efficiency came into effect in 1974. Dwellings built after this date are more energy efficient, which may decrease the fuel poverty risk for people living in them. |
| - Housing surface | Living in a large dwelling increases the probability of becoming fuel poor because energy needs are higher. |
| - Heating system | Individual boiler, wood stove or coal stove are usually associated with a high probability of being fuel poor. |
| - Heating energy source | High energy prices increase the risk of being fuel poor. |
| - Inefficiency of lighting and others electric appliances | Lighting and other electric appliances account for an increasing share of residential energy consumption (10-20%), thus the multiplication and poor energy efficiency of these appliances can lead to high energy needs. |
| - Energy efficiency | Living in an energy inefficient dwelling increases the consumption of energy and thereby the probability of falling into fuel poverty. |
| - Other dwelling attributes, *i.e.* Dampness, leaks, ventilation system, poor lighting, etc. | The presence of dampness, leaks or a broken ventilation system usually exacerbate a pre-existing fuel poverty situation. |
| Other drivers | |

*cf.* next page

47. Regardless the objective income level, there is a subjective dimension in the household's own perception of its financial endowment and quality of life. This perception can affect the amount it decides to devote to satisfy its energy needs.

Table B.1 – Complete the previous page

| Drivers | Expected effect |
|---|---|
| - Type of energy payments, *i.e.* Standard payment versus pre-payment meters | People paying with pre-payment meters are charged a higher price of energy, thereby increasing the risk of falling into fuel poverty. |
| - Climate characteristics, *i.e.* Mediterranean; Continental; Oceanic; Temperate. | Living in a hot region decreases heating needs and, therefore, the risk of being fuel poor [48]. |
| - Vehicle ownership | Owing a vehicle increases the probability of being fuel poor because of commute expenditures. |
| - Geographic location/ rural/ low urbanisation level | It seems that people living in rural areas have a higher risk of falling into fuel poverty because they do not have good access to cheap energy sources (natural gas) or competitive markets. In addition, the supply of real estate market is less important and diversified. |

48. Conversely, we note that energy needs can be high in a hot region due to the use of an air-conditioning system (*cf.* Fouquau and Bessec (2008)).

# C Description of the preliminary handling of the dataset before running the MCA

## C.1 General presentation

By definition, MCA is suitable for qualitative variables. In our initial dataset, 12 variables were qualitative and 5 were quantitative, *i.e.* “Age”, “Number of consumption units”, “Disposable income”, “Number of motor vehicles”, and “Surface of dwelling”. To be able to capitalise information contained in these quantitative variables when running our MCA we proceeded as follows.

First, in the MCA, the variables “Number of consumption units” and “Number of motor vehicles” were declared quantitative. In some cases, it is possible to include a limited number of quantitative variables in an MCA. They have the status of supplementary variables, whereas qualitative variables are incorporated as active variables. This means that quantitative variables do not contribute to the inertia (variance) of the axes of the MCA. Nevertheless, these extra variables improve the interpretation of results in terms of profile mapping.

Second, because the MCA can accommodate quantitative variables by recoding them as categorial, we introduce the three remaining quantitative variables, *i.e.* “Age”, “Disposable income”, and “Surface” after binning them into classes. In this way, they became categorial variables and were introduced in the MCA as active variables. Section C.2 below presents how we defined classes for each quantitative variable.

In sum, as presented in Table 2 from subsection 3.2, we ran the MCA by considering 15 active qualitative/categorial variables and 2 supplementary quantitative variables, where 3 of the 15 qualitative/categorial variables represent basically quantitative variables which were binned into classes.

## C.2 New classes assigned to quantitative variables to be included in the MCA

— Quantitative variable 1: “Age”
  — *5 levels*: <20years, [21-40years), [41-60years), [61-80years), >80years.

— Quantitative variable 2: “Surface”
  — *5 levels*: [1-40m2), [40-70m2), [70-100m2), [100-150m2), >150m2.

— Quantitative variable 3: “Annual disposable income”
  — *5 levels*: [0,1e+04), [1e+04,2e+04), I[2e+04,3e+04), [3e+04,4e+04), I>8e+04.

# References


G. Ambrosio, F. Belaid, S. Bair, and O. Teissier. Analyse de la précarité énergétique à la lumière de l'enquête PHÉBUS, 2015. Observatoire national de la précarité énergétique. Centre scientifique et technique du bâtiment.

M. Bennett, D. Cooke, and C. Waddams Price. Left out in the cold? New energy tariffs, low-income households and the fuel poor. *Fiscal Studies*, 23, 2002.

A. Blavier, F. Dimitropoulos, B. Faraco, and M. Moisan. Précarité energétique: état des lieux et propositions d'actions, 2011. URL `http://www.precarite-energie.org/IMG/pdf/Precarite_energetique_-_tables_rondes_departementales_V2-2.pdf_[Accessed_December_08,_2016]`. Réseau d'Acteurs Précarité-Énergie-Logement (RAPPEL).

B. Boardman. Fuel poverty: from cold homes to affordable warmth, 1991. London: Belhaven Press. ISBN: 1852931396, 978-1852931391. 224 p.

B. Boardman. Fuel poverty synthesis: Lessons learnt, actions needed. *Energy Policy*, 49, 2012.

T. Callan, B. Nolan, and C. T. Whelan. Resources, deprivation and the measurement of poverty. *Journal of Social Policy*, 22(2):141–172, 1993.

D. Charlier. La rénovation énergétique en France dans le secteur résidentiel privé. *Revue de l'OFCE In collection Débats et Politiques*, 128:395–419, 2013.

D. Charlier. Éfficacité énergétique dans le bâtiment et paradoxe énergétique : quelles conséquences pour la transition énergétique. *Revue d'Economie Industrielle*, 148:229–262, 2014.

D. Charlier and B. Legendre. Fuel poverty: a composite index approach, 2016. URL `http://faere.fr/pub/PolicyPapers/Charlier_Legendre_FAERE_PP2016.06.pdf_[Accessed_July_04,_2017]`. FAERE Policy Paper, 2016-06.

D. Charlier, A. Risch, and C. Salmon. La précarité énergétique: une discussion des indicateurs existants. un analyse empirique appliquée au cas français, 2015. Working paper, Université de Montpellier et IAE Savoie Mont-Blanc.

R. Day, G. Walker, and N. Simcock. Conceptualising energy use and energy poverty using a capabilities framework. *Energy policy*, 93:255–264, 2016.

DECC. The fuel poverty statistics methodology and user manual, 2014. URL `https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/429774/fuel_poverty_statistics_methodology_and_user_manual.pdf_[Accessed_November_30,_2015]`. Department of Energy & Climate Change. URN 15D/166. 57 p.

DETR. UK fuel poverty strategy, 2001. Department of the Environment, Transport and the Regions (DETR). London.

I. Devalière. Comment prévenir la précarité énergétique? Les leviers possibles et les risques inhérents à la libéralisation du service de l'énergie. *Les Annales de la Recherche Urbaine*, 103: 137–143, 2007.

DSDNI. Ending fuel poverty: a strategy for northern ireland, 2004. Department for Social Development Northern Ireland (DSDNI). Belfast.

DTI. Meeting the energy challenge: a white paper on energy. The stationary office, London, 2007. Department for Trade and Industry (DTI).

U. Dubois. From targeting to implementation: the role of identification of fuel poor households. *Energy policy*, 49:107–115, 2012.

N. Dutreix, C. Baecher, B. Pianu, and E. Collomb. Figure(s) de la précarité énergétique, 2014. URL http://www.urbanisme-puca.gouv.fr/IMG/pdf/figures-precarite-energetique.pdf_[Accessed_November_30,_2016]. Une synthèse réalisée par Nomadéis. Synthèse réalisée entre septembre 2013 et mars 2014 à la demande du Plan Urbanisme Construction et Architecture (PUCA).

EPEE. Diagnosis of causes and consequences of fuel poverty in Belgium, France, Italy, Spain and United Kingdom, 2006. URL http://www.powerhouseeurope.eu/uploads/tx_phecasestudies/Analysis_report_epee_3_2_EN.pdf_[Accessed_November_27,_2015]. European Fuel Poverty and Energy Efficiency (EPEE) project, EIE/06/158/SI2.447367, WP2 - Deliverable 5, 69 p.

K. Fabbri. Building and fuel poverty, an index to measure fuel poverty: an Italian case study. *Energy*, 89:244–258, 2015.

E. Fahmy, D. Gordon, and D. Patsios. Predicting fuel poverty at a small-area level in England. *Energy policy*, 39:4370–4377, 2011.

J. Fouquau and M. Bessec. The non-linear link between electricity consumption and temperature in Europe : a threshold panel approach. *Energy Economics*, 30:2705–2721, 2008.

D. Gordon, L. Adelman, K. Ashworth, J. Bradshaw, R. Levitas, S. Middleton, C. Pantazis, D. Pastios, S. Payne, P. Townsend, and J. Williams. Poverty and social exclusion in Britain, 2000. Joseph Rowntree Foundation, York.

E. Hache, D. Leboullenger, and V. Mignon. Beyond average energy consumption in the French residential housing market: A household classification approach. *Energy Policy*, 107, 2017.

J. Healy. Fuel poverty and policy in Ireland and the European Union, 2003. URL https://www.tcd.ie/policy-institute/assets/pdf/BP12_Healy_Fuel.pdf_[Accessed_February_20,_2016]. Studies in public policy. Policy Institute at Trinity College Dublin in association with Combat Poverty agency. ISBN 1-902585-10-0.

J. D. Healy and J. P. Clinch. Fuel poverty in Europe : a cross country analysis using new composite measurement, 2002. URL https://www.ucd.ie/gpep/research/archivedworkingpapers/2002/02-04.pdf_[Accessed_March_27,_2016]. Environmental studies research series working papers 02/04. ISSN 1393-9335. Department of environmental studies University College. Dublin Richview, Dublin - Ireland.

J. D. Healy and J. P. Clinch. Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in ireland. *Energy Policy*, 32: 207–220, 2004.

P. Heindl. Measuring fuel poverty general consideration and application to german household data, 2013. Discussion Paper No. 13-046. Centre for European Economic Research. 32 p.

P. Heindl and R. Schuessler. Dynamic properties of energy affordability measures. *Energy Policy*, 86, 2015.

J. Hills. Fuel poverty: the problem and its measurement. Interim report of the of the fuel poverty review, 2011. URL http://sticerd.lse.ac.uk/dps/case/cr/CASEreport69.pdf_[Accessed_January_27,_2016]. Center of analysis of social exclusion. Report 69. ISSN 1465-3001.

J. Hills. Getting the measure of fuel poverty. Final report of the fuel poverty review, 2012. URL http://sticerd.lse.ac.uk/dps/case/cr/CASEreport72.pdf_[Accessed_March_27,_2016]. Center of analysis of social exclusion. Report 72. ISSN 1465-3001.

S. Host, D. Grange, L. Mettetal, , and U. Dubois. Précarité énergétique et santé : état des connaissances et situation en Ile-de-France. *Pollution atmosphérique [En ligne]*, 223, mis à jour le : 09/01/2015, 2014. URL http://lodel.irevues.inist.fr/pollution-atmospherique/index.php?id=4580_[Accessed_April_30,_2016].

F. Husson, S. Lê, and J. Pagès. *Analyse de données avec R*. Bruxelles et Paris, Second edition, 2016. Presses Universitaires de Rennes (PUR). ISBN 978-2-7535-4869-5.

INSEE ENL. Enquête logement en 2006, 2006. URL http://www.insee.fr/fr/methodes/default.asp?page=sources/ope-enq-logement.htm_[Accessed_April_07,_2016]. Organisme responsable : INSEE, Direction des Statistiques Démographiques et Sociales (DSDS).

B. C. Isherwood and R. M. Hancock. Household expenditure on fuel: Distributional aspects, 1979. Economic Adviser?s Office, DHSS, London.

JORF. Loi n° 90-449 du 31 mai 1990 visant à la mise en oeuvre du droit au logement (1), 1990. URL http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=LEGITEXT000006075926_[Accessed_December_10,_2015]. NOR: EQUX8900132L. Version consolidée au 10 décembre 2015.

JORF. Arrêté du 15 septembre 2006 relatif au diagnostic de performance énergétique pour les bâtiments existants proposés à la vente en France métropolitaine, 2006. URL http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000788395f_[Accessed_December_03,_2015]. NOR: SOCU0611881A Version consolidée au 03 décembre 2015.

B. Legendre and O. Ricci. Measuring fuel poverty in France: which households are the most fuel vulnerable? *Energy economics*, 49:620–628, 2015.

C. Liddell, S. J. P. Morris, C.and McKenzie, and G. Rae. Measuring and monitoring fuel poverty in the uk: National and regional perspectives. *Energy Policy*, 38, 2012.

I. Mayer, E. Nimal, P. Nogue, and M. Sevenet. The two faces of energy poverty: a case study of households? Energy burden in the residential and mobility sectors at the city level. *Transportation Research Procedia*, 4, 2014.

R. Moore. Definitions of fuel poverty: implications for policy. *Energy policy*, 49:19–26, 2012.

J. P. Nicolas, F. Vanco, and D. Verry. Mobilité quotidienne et vulnérabilité des ménages. *Revue d?économie régionale et urbaine*, 1, 2012.

P. Nussbaumer, M. Bazilian, and V. Modi. Capabilities as fundamental entitlements: Sen and global justice. *Feminist economics*, 9(2-3):33–59, 2003.

P. Nussbaumer, M. Bazilian, and V. Modi. Measuring energy poverty: focusing on what matters. *Renewable sustainable energy review*, 16:231–243, 2012.

S. Okushima. Gauging energy poverty: A multidimensional approach. *Energy*, Article in press: http://dx.doi.org/10.1016/ j.energy.2017.05.137, 2017.

ONPE. Définitions, indicateurs, premiers résultats et recommandations, 2014. URL http://www.presse.ademe.fr/wp-content/uploads/2014/10/ONPE1erRapportSynthèse.pdf_[Accessed_December_3,_2015]. Premier rapport de l'ONPE (Observatoire National de la Précarité Énergétique).

ONPE. Les chiffres clés de la précarité énergétique, 2015. URL http://www.onpe.org/sites/default/files/pdf/tableau_de_bord/chiffres_cles.pdf_[Accessed_November_27,_2015]. Observatoire National de la Précarité Énergétique (ONPE). Édition numéro 1.

ONPE. Les chiffres clés de la précarité énergétique, 2016. URL http://onpe.org/sites/default/files/pdf/tableau_de_bord/chiffres-cles-precarite-energetique-novembre2016.pdf_[Accessed_January_27,_2017]. Observatoire National de la Précarité Énergétique (ONPE). Édition numéro 2.

G. Palmer, T. MacInnes, and P. Kenway. Cold and poor: an analysis of the link between fuel poverty and low income, 2008. URL http://www.poverty.org.uk/reports/fuel%20poverty.pdf_[Accessed_December_08,_2015]. Published by New Policy Institute, 3 Coppergate House, 16 Brune Street London E1 7NJ. ISBN: 978-1-902080-24-6.

L. Papada and D. Kaliampakos. Measuring energy poverty in Greece. *Energy Policy*, 94, 2016.

C. W. Price, K. Brazier, and W. Wang. Objective and subjective measures of fuel poverty. *Energy Policy*, 49:33–39, 2012.

D. Roberts, E. Vera-Toscano, and E. Phimister. Fuel poverty in the UK: is there a difference between rural and urban areas? *Energy Policy*, 87, 2015.

S. Scott, S. Lyons, C. Keane, D. McCarthy, , and R. S. J. Tol. Fuel poverty in Irland: extend, affected groups and policy issues, 2008. URL https://www.esri.ie/pubs/WP262.pdf_[Accessed_November_27,_2016]. ESRI, Working Paper No. 262, 73 p.

Scottish Executive. The Scottish fuel poverty statement, 2002. Scottish Executive, Edinburgh.

A. Sen. Inequality reexamined, 1992. AClarendon Press. ISBN: 0198283342. 224 p.

M. Smith and C. Seward. The relational ontology of amartya sen's capability approach: incorporating social and individual causes. *Journal of Humain development capabilities*, 10, 2009.

H. Thomson and C. Snell. Quantifying the prevalence of fuel poverty across the European Union. *Energy Policy*, 52:563–572, 2013.

P. Townsend. Poverty in the United Kingdom, 1979. Penguin Books, London.

C. Waddams Price, K. Brazier, and W. Wang. Objective and subjective measures of fuel poverty. *Energy Policy*, 49, 2015.

WAG. Warm homes and energy conservation act 2000: a fuel poverty commitment for Wales, 2003. Welsh Assembly Government (WAG), Cardiff.