Energy Policy 114 (2018) 189–200

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Exposure and risk to fuel poverty in France: Examining the extent of the fuel precariousness and its salient determinants

Fateh Belaïd

University Paris-Est Scientific and Technical Center for Building, 14 Boulevard Newton, Champs-sur-Marne, 77447 Marne la Vallée cedex 2, France

ARTICLE INFO

Keywords:
Fuel poverty
Energy consumption
Energy affordability
Econometric modeling
Energy efficiency

ABSTRACT

Millions of households experience fuel poverty around the world, commonly defined in broad terms in the early 1990s to cover households whose total energy bills exceeded 10% of their net income. First, this paper outlines the measurement of fuel poverty using the Low Income High Costs indicator (LIHC) and examines the main characteristics of fuel poor households in France based on multidimensional statistical analysis using a new micro-level survey data. It then explores the salient determinants of fuel poverty risk using logistic regression. About 3.18 million households are estimated to be in fuel poverty, representing 12% of all French households. The hierarchical classification suggested four distinct profiles, which shed light on the main features of fuel poor households. Additionally, results show that the risk of being fuel poor and the depth of fuel poverty increase significantly with lower EPC rating house and confirm the existence of a social gradient in fuel poverty. Recognition of this aspect can be helpful for developing economically efficient policies to address fuel poverty. This study does not aim to be exhaustive in policy implications terms, but rather to present a new way of thinking about fuel poverty solutions by targeting different household groups.

1. Introduction

The International Energy Agency estimates that 1.2 billion people lacked access to electricity, representing about 17% of the world's population in 2013 (WEO, 2015). Otherwise, a recent Buildings Performance Institute Europe report (BPIE, 2014) estimates that the fuel poverty rates in Europe fluctuate from 9.7% to 15.11% depending on the country.

According to the European fuel Poverty and Energy Efficiency report (EPEE, 2009), between 50 and 125 million people are unable to keep their home in a satisfactory thermal comfort level in Europe's 27 countries. Therefore, interest in fuel poverty has received considerable attention over the last few years and as a result there have been various studies into both the measurement of the phenomenon and its definition (Healey and Clinch, 2004; Hills, 2011; Pachauri and Spreng, 2011; Moore, 2012; Hills, 2012; Savacool, 2015; Teller-Elsberg et al., 2016). The issue is becoming important and the subject of new political awareness.

According to Thomson et al. (2016) the terms "energy poverty" and "fuel poverty" are used interchangeably within the same context. The term "Fuel poverty" is mainly used in the UK, New Zealand and Ireland, while the term "energy poverty" is sometimes used in Eastern Europe. In addition, the terms have been used interchangeably in a number of key EU policy documents (Thomson et al., 2016). In addition, Bouzarovski and Petrova (2015) stated that all forms of fuel and energy poverty, in both developed and developing countries are underpinned by a common condition: "the inability to attain a socially and materially necessitated level of domestic energy services". This paper adopts the last standpoint and refers mainly to fuel poverty given the widespread acceptance of the term throughout the industrialized countries (Liddell et al., 2012).

Households' daily life in housing accounts for more than a third of the total energy consumption and more than a fifth of greenhouses gas emissions in France (Belaïd, 2017; Lévy and Belaïd, 2018). The impact of limited income and rising energy costs on people's ability to 'keep warm' in their homes has been the subject of much recent debate in France. Over the past decade, significant attention has been paid to the issues of fuel poverty, as evidenced by the creation of the French National Fuel Poverty Monitoring Agency in 2011. Fuel poverty therefore represents an important research area for generating the knowledge needed for the improvement of fuel poverty interventions (Bair et al., 2017).

Recently, the French government has had in place a number of measures that are designed to tackle fuel poverty, including the "Better Living"[1] program, introduced in 2010, and the French National Fuel Poverty Monitoring Agency (ONPE) founded on March 2011. This has

E-mail addresses: fateh.belaid@cstb.fr, fateh.belaid@univ-littoral.fr.

[1] "Habiter Mieux" in French.

https://doi.org/10.1016/j.enpol.2017.12.005
Received 10 June 2017; Received in revised form 3 December 2017; Accepted 5 December 2017
Available online 22 December 2017

been part of an attempt to reconsider the actual fuel poverty policies and set a durable framework for future programs aiming to tackle the phenomena.

Fuel poverty is associated with cold homes and negative health outcomes. Nevertheless, France's residential dwellings stock is composed of relatively energy inefficient housing units, which can result in houses that are challenging or costly to heat (Lévy et al., 2014; Belaïd, 2016; Belaid and Garcia, 2016). Despite the lack of coherent and clearly standard definition, the relevance of the issue as well as the harmful health effects of cold homes are extensively recognized, including respiratory problems, excess winter deaths, increased risk of poor mental health and circulatory problems (Liddell and Morris, 2010; Shortt and Rugkåsa, 2007; Howden-Chapman et al., 2012).

Analyzing fuel poverty problem is crucial to improve the formulation of future policies and important for programs required to deal with energy poverty. However, this study aims to provide information that answer to the following questions: How should we quantitatively measure fuel poverty? What are the main features of fuel poor households in France? What are the salient factors affecting the risk of being fuel poor?

This article particularly focuses on the challenges of measuring the extent and understanding the impact various houses and socio-economic factors have on the risk of being fuel poor under the LIHC measure. More precisely, the logistic model allows us to predict a probability and calculate how a change in a set of known characteristics (socioeconomic characteristics and habitation attributes) affects the odds of being fuel vulnerable.

The fuel poverty indicator used in this study is based on household energy bill and income (incomes calculated after housing costs). The foundation for our approach is inspired by the ground-breaking study of Hills in the UK (Hills, 2012). It is based on PHEBUS,[2] a recent survey containing a wealth of information on the household attributes, occupants' energy uses and behaviors, dwelling characteristics as well as on all aspects of energy precariousness (housing and transport).

In embarking on this path, this study contributes to the literature on fuel poverty in several ways. Firstly, it measures the level of fuel poverty and gives a detailed description of households' profile that suffer from fuel poverty and gives an update on the typical fuel vulnerable household in France based on a very recent and rich survey. Clusters are especially helpful in examining policy opportunities oriented towards specific household groups. Secondly, it explores the household and dwelling attributes that are prominent in driving households to a precarious energy situation. Thirdly, this paper contributes to enriching knowledge on the salient drivers of fuel poverty in France, which can be subsequently used to support decision making in energy policy design. In fact, there is a shortage and non-availability of individual micro-data on household energy demand, to the best of our knowledge, and empirical research on dwelling- and household-related factors that affect fuel poverty is rather limited. Furthermore, from a policy-making point of view, this approach provides a framework to developing more effective energy policies and ambitious fuel poverty reduction schemes geared towards specific households (e.g. refurbishment of the existing dwellings, helping households living in poorly insulated homes, additional information and data on household lifestyle and behaviors, etc.).

The remaining part of this paper is built up as follows: Section 2 gives a brief overview and discusses the prior literature relating to fuel poverty. Section 3 describes the data and the modeling procedure. We present our empirical results and discuss their implications in Section 4. Section 5 concludes and provides some possible policy implications of our main findings.

[2] PHEBUS is a French acronym: Performance de l'Habitat, Équipements, Besoins et USages de l'énergie corresponding to "Housing performances, equipment, needs, and usages of energy".

2. Overview of fuel poverty and literature review

2.1. Fuel poverty overview and definition

Fuel poverty is an issue that is growing in both recognition and prevalence across the world. Over the last decades, fuel poverty has been recognized as a form of environmental inequality and as an unacceptable feature in contemporary society (Boardman et al., 1999; Wilkinson et al., 2007; Walker and Day, 2012; Sovacool, 2015). Nevertheless, determining whether a household is fuel poor is a complex issue strongly related to a large number of inter-connected factors, including income, fuel bills as function of the rate of energy price increases, and domestic energy needs (dependent on dwelling energy efficiency, behavior and the lifestyle of householders).

Fuel poverty first arose in the late 70 s and early 80 s in the UK and knowledge on fuel poverty and related concepts is primarily focused in the UK and Ireland. The first studies on fuel poverty phenomenon focused, in principal, on the definition and quantitative measurement of fuel poverty levels.

Many authors attempted to define fuel poverty since the 1980s (e.g. Lewis, 1982; Bradshaw and Hutton, 1983; Boardman, 1991, 2012; Buzar, 2007; Moore, 2012; Bouzarovski et al., 2012; EESC, 2013; Thomson et al., 2016). According to Papada and Kaliampakos (2016), these definitions can be summarized as the difficulty or inability of a household to afford an adequate coverage of its energy needs due to high energy bills, low incomes, and the dwelling's energy inefficiency. Richardson (1978) is credited with being among the first to draw the first definition of fuel poverty, characterizing it as a situation where people lack the resources to "*afford the cost of the fuel they need for heating, lighting and cooking*". In 1991, fuel poverty was given a more tangible definition by Brenda Boardman. Under this definition, a household is considered to be fuel poor if its expenditure on energy services exceeds 10% of its net income.

The 10% measure was criticized as being inappropriate since it relies on observations made more than 25 years ago by Boardman (1991) and is strongly sensitive to changes in fuel prices (Moore, 2012). According to Moore (2012), the 10% threshold does not target those most in need. Moore (2012) asserted that the income composition and thresholds govern the distribution of the target populations and the relative importance of the main drivers of fuel poverty.

According to Thomson et al. (2016), fuel poverty studies in the rest of Europe is less developed, even if a wider range of single country studies have been conducted. Thomson et al. (2016) stated that the multiplicity of both concepts and definitions of fuel poverty is problematic and argued that a broad common definition is crucial for raising the profile of fuel poverty and ensuring it is recognized as a policy issue by the EU member countries. The authors highlighted that contrary to the European Commission's stance, many of the EU institutions are in favor of a common EU definition of fuel poverty, and have been arguing for the establishment of a definition for at least seven years.

In France, greater importance has been accorded to the issue of fuel poverty since the middle of the past decade. However, policy and action in this area is still partial. The main efforts focused on discussing the results of fuel poverty (e.g. gas and electricity debts) rather than dealing with its causes.

The problem of energy affordability entered the political debate in 2004, as a result of increases in domestic energy prices. A primary impetus lies on creating a network of fuel poverty actors in 2007, called RAPPEL.[3] Then, the fuel poverty problem was discussed at the Grenelle roundtable. This resulted in a first wave of studies aimed at assessing the extent of fuel poverty in France. The results of these studies indicated that approximately 3.4 million households were in fuel poverty in France. The resulting legislation led to the inclusion of fuel poverty in

[3] Réseau des Acteurs de la Pauvreté et la Précarité Energétique dans le Logement.

the “Grenelle II” law[4] in 2010.

Under the “Grenelle II” definition, a person is considered as fuel poor: “*person who meets, in his home, particular difficulties to have the necessary energy to meet his standard energy needs owing to his low income or to his poor housing conditions*”. The French fuel poverty strategies drew heavily on UK's 10 per cent threshold. However, the fuel poverty indicator based on the 10% threshold used in France differs from its original British version. The British version is based on modelled energy requirements, whereas the French version is based on real declared energy consumption. However, households restricting their energy consumption would not be identified as fuel poor when using declared energy consumption (Imbert et al., 2016).

Since 2010, the French Ministry of Ecology and Sustainable Development has revived its interest in fuel poverty and initiated a new fuel poverty scheme, called “Better Living”.[5] The program started in 2011 and aimed to help low-income owner-occupiers to improve the energy performance of their properties.

2.2. Fuel poverty measurement

Since the early 2000s, fuel poverty has gained popularity both in policy and academia. A growing literature has focused on fuel poverty measuring and monitoring (Liddell et al., 2012; Sovacool and Dworkin, 2015; Teller-Elsberg et al., 2016; Papada and Kaliampakos, 2016).

Theoretical, as well as some empirical, papers on the fuel poverty measurement are now numerous with a wide range of reported results for different countries. Liddell et al. (2012) retraced the earliest formulation of the fuel poverty concept in the UK, focusing mainly on the 10% needs to spend threshold which was adopted in 1991 to define fuel poverty. The authors argued that understanding more about the origins of this threshold yields a more critical understanding of why fuel poverty targets in the UK have not been reached, and enables a more informed approach to setting realistic targets for the future.

Findings of a comparative institutional analysis by Healy (2001) assessing housing conditions and fuel poverty in 14 European Union states including Ireland revealed that Southern Europe suffers from the highest levels of fuel poverty and the poorest housing conditions. The highest rate of fuel poverty is observed in Portugal. Elsewhere in Northern Europe, Belgium, France and Ireland also demonstrated relatively high levels of fuel poverty. Such results are remarkable when it is considered that these three countries all enjoy living standards considerably above the EU-average. The main conclusion of Healy's research is that while poverty could in theory be tackled through rising incomes with some income redistribution, fuel poverty needs more coordinated policy action not only through taxation or benefits, but also in crucial investment in household capital stock. The Buildings Performance Institute Europe (BPIE, 2014) reported similar findings. According to this study, based on 2012 Eurostat data, Bulgaria, Hungary, Greece and Cyprus were the most fuel poor countries in the EU.

Sovacool (2015) examined how dwelling energy efficiency schemes in England can decrease the prevalence of fuel poverty. In addition, this study explored the “Warm Front” program in UK. This scheme intends to tackle fuel poverty by providing grants for insulation and heating measures to householders who struggle to heat their homes (private rental and owner-occupier households). Sovacool's research details the challenges and the benefits of the scheme and it teases out six lessons for energy policymakers. Thus, Warm Front program proves the truly huge financial benefits of investing in energy efficiency measures and highlights the vital importance of human behavior in determining whether energy efficiency programs succeed or fail.

More recent research also reported different results on the fuel poverty measurement depending on the type of the definition and data used. Teller-Elsberg et al. (2016) investigated the severity and the extent of fuel poverty in Vermont using data from the Census Bureau's American Community Survey. The results of this study indicated that about 71,000 people suffered from fuel poverty in Vermont in 2000, and in 2012 the number rose to 125,000. Despite major efforts by local and state actors, fuel poverty has grown by 76% during this period. In addition, this study demonstrated that excess winter deaths, caused potentially by fuel poverty, kill more Vermonters each year than car crashes.

Based on primary survey covering objective data of energy expenses as well as subjective perceptions about housing conditions, Papada and Kaliampakos (2016) highlighted the great vulnerability of Greek households to fuel poverty, in the middle of a severe economic crisis. This study estimated that under the objective expenditure-based method, 58% of Greek households are energy poor. In addition, among households under the poverty threshold, the energy poverty rate exceeds 90%.

Recent research conducted by Thomson et al. (2017) examined the available statistical options for monitoring energy poverty. This study highlights how the paucity of suitable data at the EU level may be problematic for several reasons, chiefly because the lack of data limits the measures that can be applied universally as well as prevents rigorous assessment of energy poverty across the EU.

More recently, Bouzarovski and Tirado Herrero (2017) conducted a comprehensive analysis of spatial and temporal trends in the national-scale patterns of energy poverty, as well as gas and electricity prices. The findings of this study suggest that the classic economic development distinction between the core and periphery also holds true in the case of energy poverty, as the incidence of this phenomenon is significantly higher in Southern and Eastern European EU Member States.

2.3. Modeling factors affecting fuel poverty exposure

Most recently, a new line of standard research has focused on the modeling factors affecting exposure and risk to fuel poverty. Masuma (2013) used a logistic regression model to examine the effects of household and dwelling characteristics on the risk of being fuel poor under the LIHC measure in the UK. This research was based on the 2009 and 2010 English Housing Survey data. The results indicated that the main exacerbating factors of fuel poverty are: household size, employment status, useable floor area, housing type and HRP age. For example, the risk of being fuel poor is higher for a single person than for larger households. Exposure and risk to fuel poverty increase significantly for dwellings with floor area above $50\,m^2$. In addition, households living in social housing units were at low risk of being in fuel poverty compared to households in private rented properties. The results concluded that household attributes coupled with high-energy bills and low resources tend to exacerbate households exposure to fuel poverty.

Thomson and Snell (2013) conducted an EU-wide comparative study of fuel poverty using standardized EU-Statistics on Income and Living Conditions data from 2007. They explored the drivers affecting household's exposure to fuel poverty using a multi-variate logistic regression model. Their regressions revealed that the location of the dwelling (rural or urban area) has a large impact on the probability of being fuel-poor. This is especially true for rural areas where higher levels of poverty are found (Macours and Swinnen, 2008). The inability to keep a home adequately warm, as well as arrears on energy bills has a large effect on the probability of living in a home with dampness, leaks, or rot. Similarly, the inability to keep a home adequately warm has a large effect on the probability of the household accruing arrears on energy bills. Thomson and Snell (2013) argued that the three proxies are much correlated. If a household is struggling to pay energy bills and can hardly afford to heat their dwelling adequately, they are likely to reduce their consumption of energy, which will most probably cause rot

[4] http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022470434&categorieLien=id.

[5] “Habiter Mieux” in French.

and damp. In terms of health costs associated with cold and damp housing, Boardman and Hunt (1994) argued that illnesses related to poor dwelling put a significant additional pressure on health services resources in the UK and estimated that these diseases cost around £1 billion a year.

Healy and Clinch (2004) intended to assess the severity of fuel poverty and domestic energy efficiency levels in Ireland based on self-reported data. They conducted a socio-demographic and socio-economic analysis in order to identify groups that suffer the most from fuel poverty, as well as the reasons behind the lack of investment in energy-saving schemes. In addition, they examine the relationship between adverse housing conditions and fuel poverty. Therefore, they proposed a logistic regression analysis to explore the variables that influence the risk of fuel poverty. Their results demonstrate that Ireland suffers from similar levels of fuel poverty as the UK, with low-income households suffering the greatest. Furthermore, the results revealed that the fuel allowance is a necessary but insufficient strategy in addressing fuel poverty.

Recently, Legendre and Ricci (2015) used a logit, a C log–log and a mixed effect logit model to examine which factors influence the odds of being fuel vulnerable using the French 2006 National Housing Survey. The results support that the proportion of fuel poor households and their attributes differ substantially according to the fuel poverty indicator used. The results of the logistic model suggest that the risk of being fuel poor is higher for the single person households, in rented properties, with inefficient roof insulation, with an individual heating system, and using gas for cooking. Empirical fuel poverty studies in France is less developed, even if a wider range of approach has been used (Legendre and Ricci, 2015).

In view of the ongoing interests and debate on fuel poverty, this research intends to evaluate the extent of fuel poverty and examine the salient determinants of fuel poverty risk in France. In addition to contributing to the ongoing research and debate on fuel poverty phenomenon, this article introduces at least three novelties. Firstly, as far as we know, empirical research dealing with this issue in France is rather limited, due to the lack of information and availability of disaggregated data on household energy usages. Secondly, it explores and reveals a lot about the various factors affecting exposure and risk to fuel poverty. Therefore, this paper contributes to enriching knowledge of the salient drivers of fuel poverty, which can be subsequently used to support decision making in energy policies and programs formulation.

Thirdly, the multivariate statistical analysis used in this study will provide a valuable description of households' profiles that suffer from fuel poverty, which could help inform targeted fuel poverty-awareness campaigns.

3. Data and methodology

3.1. Data

This study is based on the micro-data from the recent household energy consumption survey PHEBUS, conducted by the French Department of Observations and Statistics (SOeS) under the Ministry of Ecology and Sustainable Development. This study relied on the latest version of the PHEBUS micro level data released in early 2014. The main objective of the survey was to provide a better view of energy performance of French housing units. PHEBUS is a timely cross-sectional survey, with a national representative sample of French residential dwelling sector consisting of 2356 households in dwellings statistically selected to represent about 27 million housing-units. The basic random sample stems from a complex stratified multistage sampling design. This survey contains two parts: the first part is a face-to-face interview with the responsible household family member; the second part is an energy performance diagnosis of the dwelling diagnosis carried out by certified professionals. The survey affords a detailed overview of the dwelling-units situation occupied as primary residence and energy performance-related data of the residential housing stock. PHEBUS survey variables include the occupant socio-demographic attributes, the technical aspects of the housing units, energy use and behavior, home appliances, energy systems and related consumption. Moreover, it includes valuable information on dwelling energy efficiency. Thus, it is the first database containing both observed and theoretical households energy consumption.

3.2. Empirical approach

To accomplish the stated research objectives, the empirical analysis is divided into three main stages. The step intends to measure the level of fuel poverty in France, based on the LIHC indicator. We define, in the second step, the profiles of the households identified as fuel-poor under the LIHC indicator based on an explanatory statistical technique, including Multiple Correspondence Analysis (MCA) and Ascending Hierarchical Classification (AHC). Finally, in the third phase, we developed a logistic regression model relating fuel poverty with some factors, including the employment status of HRP (Household responsible person), age of HRP, race, occupancy status, etc. Based on a set of known characteristics, the results of the model provide odds and population attributable risk to exposure to fuel poverty.

3.2.1. Fuel poverty measurement

The empirical measurement of fuel poverty is based on the LIHC indicator, in which a specific population is counted as fuel vulnerable if having both high energy bill and low income. In fact, this approach establishes two thresholds:

i. Income threshold: depicted as 60% of the national median equivalised residual income (i.e. after housing costs deduction, including mortgage and rent payments) plus the individual household's energy bill;
ii. Energy costs thresholds: depicted as the median equivalised energy cost for all households (at the national level).

Fig. 1 illustrates the definition of fuel poverty under the LICH measure and the fuel poverty gap.

The LIHC indicator is a twin indicator (Hills, 2012) that depicts:

– The extent of fuel poverty, i.e. *number* of households that have both a residual income below the poverty line and energy costs higher than the national median level;
– The depth of fuel poverty, which provides a measure of fuel poverty severity. It is measured by the so called *fuel poverty gap* (shown by the horizontal arrow in Fig. 1). It measures the extent to which a household falls below the energy costs threshold. In other words, the abatement in energy bill intended to lift the household out of fuel

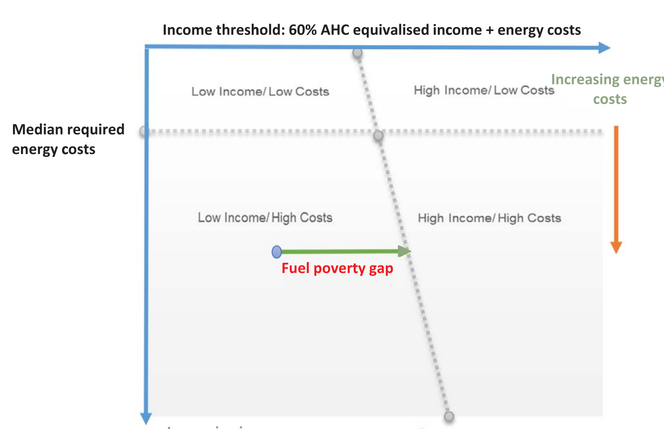

Fig. 1. Fuel poverty measurement under the LIHC indicator.

poverty.

The objective of this indicator is framed as finding and targeting the most vulnerable energy consumers. While it has some strengths, LIHC as it currently stands also has serious weaknesses. Its main shortcoming is that high costs threshold, because of its use of total rather than unit (€/m^2) energy costs (the high energy cost threshold), it focuses on large, under-occupied housing-units. This leads to eliminate many low-income households living in energy inefficient small properties. Therefore, in this study, to overcome this shortcoming we proposed an alternative indicator using unit (€/m^2) energy costs threshold. Accordingly, the high energy cost threshold is set at the national median equivalised fuel cost per m^2 (€/m^2).

3.2.2. Multiple correspondence analysis and ascendant hierarchical clustering

The aim of this section is to aggregate the population into homogenous groups, which would correspond to distinct households typologies considered to be fuel poor profiles based on certain housing and household characteristics. Therefore, we employed a clustering method based on the multi-correspondence analysis followed and ascendant hierarchical clustering.

MCA is often processed as first step of classification procedure. In a case where we face a large dataset, MCA is used to spot the more discriminating variables and to reduce the dataset dimensions by building synthetic variables that are defined as linear combinations of them. This methodology helps us to summarize the data in an optimal way as it results in a limited number of orthogonal variables that are called factor or principal components. The method considers large dataset as “clouds” of points located in a multidimensional Euclidean space. To describe the patterns in a geometrical way, each variable of analysis is seen as a point at which coordinates are given in a low-dimensional space. Thanks to graphical presentation that produces two dual displays whose row and column geometries have similar interpretations, connections linking categorical or categorized variables are easily identifiable. We cannot obtain this duality in other multivariate statistical approaches. Moreover, MCA does not need to meet assumption requirements as other widely spread technics do when analyzing categorical data (e.g., Fischer's exact test, Chi-square analysis, ratio test, and G-statistics,) (Aktürk et al., 2007).

The second step of the procedure is the ascendant hierarchical clustering (AHC). This step consists of partitioning the population into homogeneous groups based on the inputs produced by the MCA. AHC uses the coordinates of each individual on the axes previously selected. AHC proceeds by leading a series of subdivisions to group individuals and results in the construction of a ‘family tree’ or dendrogram of groups based on the pairing of the closest observations.

As the tree must be split into classes, the choice of aggregation criteria is needed. There are a variety of different measures of inter-cluster distance, e.g. Ward's criteria, single linkage average linkage and complete linkage. However, the Ward's criteria (Ward, 1963) are the most commonly used in the literature. Initialization stage consists of having as many clusters as number of individuals. Then, at each step, the closest clusters are aggregated and merged in order to minimize the within-types variance and to maximize the between-types ones. Juxtaposition of these provides the criterion that is used to choose the number of types to retain.

Compared to other clustering methods (e.g. SOM-based clustering), the AHC has many advantages: (i) easy implementation regarding different kinds of attributes; (ii) facility to manage any form of similarity; and (iii) distance and flexibility regarding the level of granularity. Finally, the method allows to have a large representation of data without needing to preset the number of clusters (Abdelmalek et al., 2010).

The definition and list of factors used in clustering procedure provided in Table 1.

Table 1
List and description of classification variables.

Variable	Categories	Frequency
Household income (per quartiles) (HI)	Less than 9490 €	24.75
	From 9491 to 11,540 €	25.25
	From 11,541 to 14,081 €	24.75
	More than 14,082 €	25.25
Number of household members (NHM)	1	33.84
	2	16.16
	3 – 4	34.34
	> 5	15.66
Tenure type (TT)	Owner	43.43
	Rented	56.57
Employment status (ES)	Top managerial and intellectual profession (TMIP)	4.55
	Intermediate profession (IP)	11.11
	Employees (EM)	37.37
	Workers, routine and manual occupations (WRMO)	37.37
	Other	9.60
Actual occupation status (AOS)	Employed [a]	55.05
	Retired person	18.18
	Unemployed	15.66
	Other	11.11
Gender	Male	52.53
	Female	47.47
Nationality	French	20.71
	Other	79.29
Age (per quartiles)	Less than 39	22.73
	From 40–48	26.77
	From 49–56	23.74
	More than 57	26.77
Total square footage (per quartiles) (TSF)	Less than 59 m^2	24.75
	From 60–73 m^2	24.75
	From 74–91 m^2	26.26
	More than 92 m^2	24.24
Building Proximity to other households (BPH)	Isolated individual house (IIH)	25.76
	Semi-detached house (SDH)	21.72
	Shared building (SB)	52.53
Construction year	Before 1975	67.68
	After 1975	32.32
EPC	A-B-C	12.82
	D	22.05
	E	28.72
	F-G	36.41
Heating system (HS)	Shared central (SC)	18.18
	Individual central (IC)	72.22
	Other	9.60
Heating energy	Electricity	27.78
	Gas	48.99
	Oil	13.64
	Other	9.60
Urban structure (US)	Rural commune (RC)	18.69
	From 2000–20,000 inhabitants	20.71
	From 20,000–200,000 inhabitants	15.15
	More than à 200,000 inhabitants	24.75
	Paris conurbation (PC)	20.71
Heating temperature (HT)	Less than 20°	39.39
	From 20–21°	30.30
	more than 21°	30.30
Climate zone	H1	66.16
	H2	24.75
	H3	9.09

3.2.3. Empirical specification

The purpose of this section is to develop a model to predict the odds of being in fuel poverty under the LIHC indicator based on household and dwelling attributes. Logistic regression was used to examine the respective effects of dwellings and occupant attributes on the risk of energy precariousness. The choice of logistic regression is motivated by its capability to investigate whether the patterns often observed across fuel poverty are in fact associated with a unique factor or an association of a number of factors.

It is widely regarded as the statistic of choice for situations in which the occurrence of a dichotomous outcome is to be predicted (Hosmer and Lemeshow, 2000).

The general logistic regression model with one covariate can be written as:

$$\log[p/(1-p)] = \beta_0 + \beta_i x_i$$

Where p is the probability of the outcome of interest, x_i are the values of potential predictor variables, β_0 is an intercept term, β_i are the coefficients associated with each variable, and i is a unique subscript denoting each variable.

The habitual assumption is that predictor variables are associated in a linear manner to the log odds $\{\log[p/(1-p)]\}$ of the outcome of interest.

The dependent variable of interest is Y_i.

Y_i is a binary response variable. We define:

$$Y_i = \begin{cases} 1, & if\ \ the\ \ houshold\ \ is\ \ fuel\ \ poor \\ 0, & otherwise \end{cases}$$

The model is given by the form below:

$$Y_i = \beta_0 + \sum_i \beta_i x_i + \varepsilon_i$$

Where x_i are the explanatory variables (e.g. employment status) and ε_i is the error term.

Table 2 reports the list of variables used to model the fuel poverty risk.

4. Results and discussion

4.1. Fuel poverty measurement

According to the LIHC indicator employed in this research, around 3.18 million families are living in fuel poverty, the equivalent of approximately 12.1% of all French households. Fig. 2 depicts all households found to be fuel poor by LIHC indicator based on real declared energy consumption. Red dots represent households that are fuel poor under LIHC indicator.

The average fuel poverty gap in France (difference between actual and affordable fuel costs) was estimated to reach €615. Fig. 3 reports the distribution of fuel poverty rates and the depth of fuel poverty by different EPC bands under LIHC indicator. We see from Fig. 3 that the fuel poverty gap and rates of fuel poverty increase as the energy efficiency of the dwelling decreases. About 40% of families occupying F and G rated properties are fuel poor, whereas only 10% of families occupying A-B-C rated properties are under fuel precariousness. In addition, the depth of fuel poverty is higher in F-G rated habitations compared to A-B-C, D and E rated habitations. The average fuel poverty gap is about €672 in F-G, €435 in A-B-C, €408 in D and €458 in E rated properties.

The average fuel poverty gap is higher for households living in A-B-C rated properties than households living in D rated habitations. In fact, caution should be taken when looking at the fuel poor in A-B-C rated homes as the number of households in this group are quite small. This result is consistent with the findings of Masuma (2013), who concluded that the depth and proportion of fuel poverty increase markedly with poorer energy efficiency scores. Overall, the findings support the hypothesis that both the likelihood and depth of fuel poverty decreases as the housing energy efficiency increases.

4.2. Households fuel poor profile

The multivariate statistical analysis tells a lot about the distinctive characteristics of fuel poor household profiles, including socio-economic attributes and housing conditions. The result was a rotated component matrix consisting of five factors for 63% of the inertia. The

Table 2
List and description of modeling variables.

Variable	Categories	Frequency
Number of household members (NHM)*	1	22.90
	2	36.20
	3 − 4	32.85
	More than 5[a]	8.05
Tenure type (TT)*	Owner	76.15
	Rented[a]	23.85
Employment status (ES)*	Top managerial and intellectual profession	18.17
	Intermediate profession[a]	22.99
	Employees	22.77
	Workers, routine and manual occupations	25.83
	Other	10.25
Actual occupation status (AOS)*	Employed[a]	51.79
	Retired person	38.74
	Unemployed	4.48
	Other	4.99
Gender*	Male	68.40
	Female[a]	31.60
Nationality	French[a]	91.05
	Other	8.95
Age (per quartiles)	Less than 44	24.32
	From 45–56	25.61
	From 57–66	23.50
	More than 67[a]	26.56
Total square footage (per quartiles) (TSF)*	Less than 66 m^2	24.06
	From 67–86 m^2	25.67
	From 87–110 m^2	25.13
	More than 111 m^2[a]	25.13
Building Proximity to other households (BPH)	Isolated individual house	50.11
	Semi-detached house	21.33
	Shared building[a]	28.56
EPC	A-B-C	15.94
	D	27.31
	E	29.62
	F-G[a]	27.13
Heating system (HS)	Shared central	9.69
	Individual central[a]	76.97
	Other	13.34
Heating energy (HE)*	Electricity[a]	34.35
	Gas	38.87
	Oil	15.54
	Wood	5.98
	Other	5.25
Urban structure (US)	Rural commune	24.88
	From 2 000–20,000 inhabitants	18.30
	From 20,000–200,000 inhabitants	18.21
	More than à 200,000 inhabitants	24.92
	Paris conurbation[a]	13.69
House refurbishment (HR)*	Yes	50.06
	No[a]	49.94

* Variable included in the final model.
[a] Reference group.

AHC was performed on these five factors (axes). Four distinct and homogeneous types were formed corresponding to the features of households. Fig. 4 and Fig. 5 display the factor map and the hierarchical clustering on the factor map respectively.

Table 3 provides a description of the households profiles depicted as fuel-poor under the LIHC indicator. The different profiles may be described as follows:

- Foreign family, employed, in shared building group: represents 24% of the sample.
- Single person, retired, in small size flat group: *accounts for 23%* of the sample.
- Family in individual house with gas and individual central heating system group: *covers 32%* of the sample.

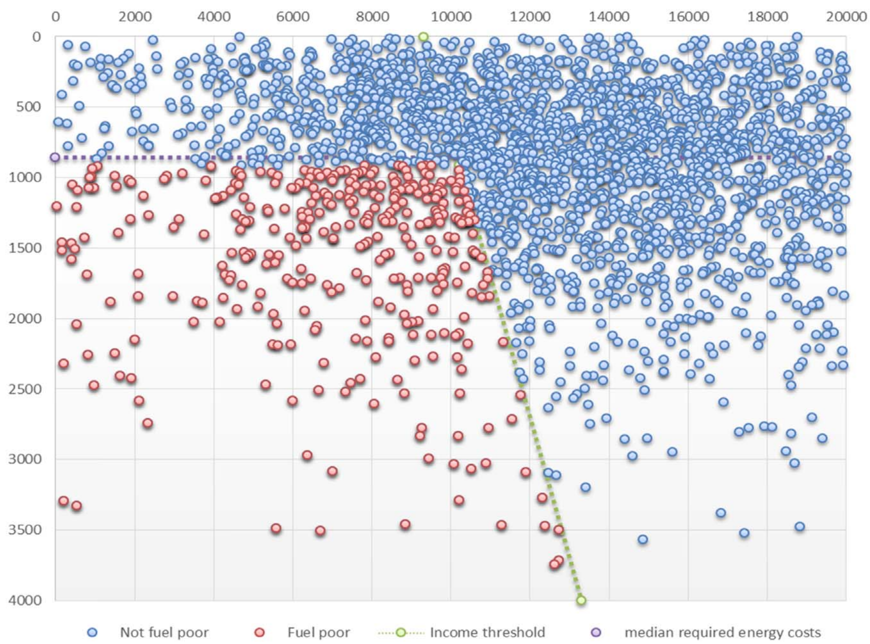

Fig. 2. Households classed as fuel poor in France under the LIHC indicator.

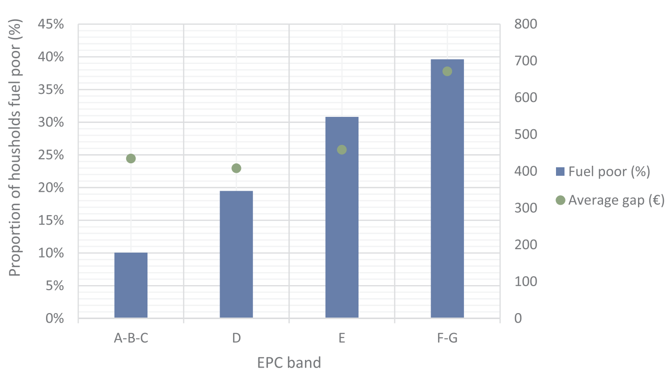

Fig. 3. Fuel poverty and average fuel poverty gap by EPC rating bands.

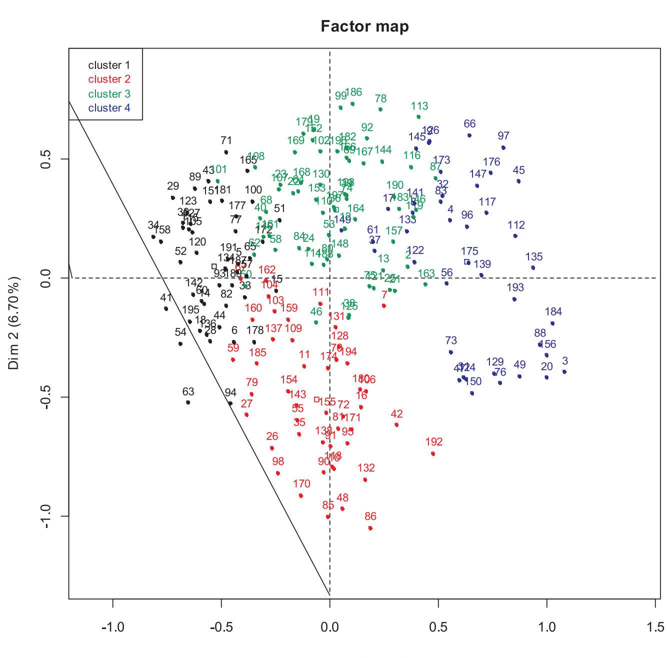

Fig. 4. Factor map and clusters.

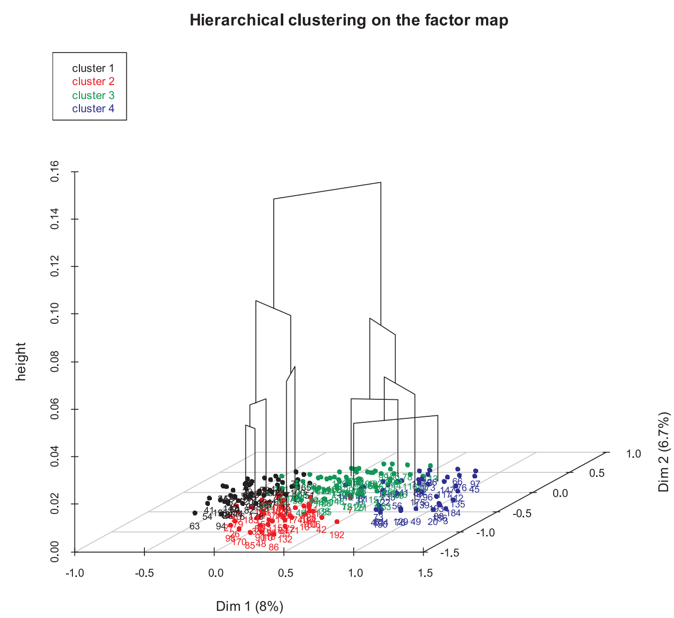

Fig. 5. Hierarchical clustering on the factor map.

– Owner of high size rural house group: *represents 21%* of the sample.

MCA and AHC identified have identified four different household profiles to serve as a basis for targeted policy interventions. Therefore, the results of this research provide a new outlook to help shape future policies that are better targeted towards identifiable groups of households that are more likely to experience fuel poverty.

4.3. Logistic regression results

The logistic regression results show that most of the coefficients, particularly those associated with number of household members and total square footage, are significant at the 1% level. The Hosmer and Lemeshow test (Hosmer and Lemeshow, 2004) is statistically insignificant at the 1% level, which validate our logistic model. In addition, this model offers a very good level of discrimination. The Receiver Operating Characteristics Curve (ROC) (Gardner and Greiner, 2006), is

Table 3
Profiles description of the households identified as fuel-poor under the LIHC indicator.

	Composition of cluster		
	Household	Dwelling	Energy
Cluster 1 (24%): Foreign family, Employed, in shared building with shared central heating system	A family (28%), foreign (58%), employed (72%)	Shared building (100%), medium footage size (43%), in big cities (66% in Paris conurbation)	Shared central heating system (70%) with other energies (23%)
Cluster 2 (23%): single person, retired, rented, small size in shared building	Single person(87%), female(67%), retired person (46%), old age (56% more than 57 years)	Rented (85%), small flat (63%) in shared building (91%)	Individual heating system (91%), electric heating (50%)
Cluster 3 (32%): Family 3–4 person), in individual house with gas individual central heating system.	Family composed of 3–4 members (47%), age 40–48 years (41%)	Semi-detached house (55%), D EPC rating band (34%)	Individual heating system (99%), gas heating (70%)
Cluster 4 (21%): Owner of high size individual house in rural areas with oil heating energy.	French nationality (95%), age: 49–56 years (40%)	Owner (71%), Isolated individual house (81%), rural areas (59%), F-G EPC rating band (40%), high size (41% more than 92 m^2)	Other heating system (30%), oil heating (51%)

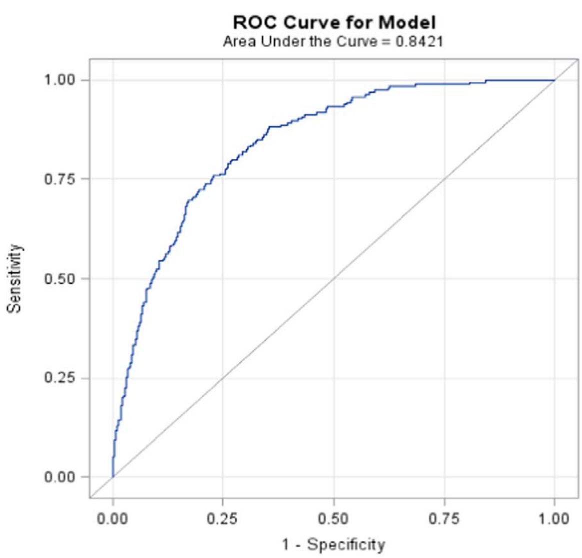

Fig. 6. Logistic model ROC curve.

Table 4
Logistic regression results.

Odds ratio estimates				
Effect	Hills	Point Estimate	95% Wald Confidence limits	
AOS: Other vs. employed	Fuel poor	1.382	0.783	2.438
AOS: Unemployed vs. employed	Fuel poor	2.565	1.511	4.354
AOS: Retired person vs. Employed	Fuel poor	0.534	0.338	0.842
ES: Other vs. IP	Fuel poor	1.873	0.935	3.751
ES: TMIP vs. IP	Fuel poor	0.518	0.223	1.201
ES: EM vs. IP	Fuel poor	2.439	1.442	4.124
ES: WRMO vs. IP	Fuel poor	2.209	1.306	3.737
NHM: 1 pers. vs. More than 5	Fuel poor	0.527	0.278	0.999
NHM: 2 pers. vs More than 5	Fuel poor	0.239	0.126	0.455
NHM: 3 − 4 pers. vs. More than 5	Fuel poor	0.446	0.258	0.771
Nationality: Other vs. French	Fuel poor	1.604	1.014	2.539
Gender: Male vs. Female	Fuel poor	0.683	0.463	1.006
TSF: < 66 m^2 vs. More than 111 m^2	Fuel poor	6.170	3.272	11.634
TSF: 67–86 m^2 vs. More than 111 m^2	Fuel poor	4.143	2.346	7.316
TSF: 87–110 m^2 vs. More than 111 m^2	Fuel poor	2.823	1.597	4.988
Tenure type: Owner vs. Rented	Fuel poor	0.529	0.366	0.765
House refurbishment: Yes vs. No	Fuel poor	0.686	0.489	0.922
Heating energy: Gas vs. Electricity	Fuel poor	1.580	1.076	2.321
Heating energy: Oil vs. Electricity	Fuel poor	2.196	1.282	3.760
Heating energy: Wood vs. Electricity	Fuel poor	0.911	0.342	2.430
Heating energy: Other vs. Electricity	Fuel poor	0.942	0.459	1.932

employed to examine the model accuracy in discriminating between fuel poor and non-fuel poor households. Fig. 6 displays the ROC curve from our analysis.

As we can see from Fig. 6 our ROC curve is well above this line. C-statistic, i.e. the area under our curve (AUC) is 0.842 as compared to that of the diagonal line which is always 0.500 (half the graph). In fact, AUC can range from 0.5 (no predictive ability) to 1 (perfect discrimination).

Estimation results are given in Table 4. Effects of the various factors on the risk of fuel precariousness are graphically shown in Fig. 7.

4.3.1. Household composition: Larger families are more fuel vulnerable compared to single-person households

The logistic results suggest, among household characteristics, that composition of the household was one of the most influential elements on the risk of fuel poverty in France. We show evidence that larger families are more likely to experience fuel poverty. For example, the odds of families with five or more occupants are almost two times that of single-person households, all things being equal. The odds of being fuel poor are four times lower for families with two persons than for large families with five or more occupants. This is different to findings reported by Legendre and Ricci (2015), which concluded that living alone is correlated with a high risk of fuel poverty. It is also different from the result of Masuma (2013), who argued that a single-person has higher risk to fuel poverty exposure than larger families. One possible explanation of this result is that, due to its use of unit (€/m^2) energy costs rather than the total energy costs (€), the LIHC indicator used in this study includes many low income and large families living in smaller properties of poor energy efficiency. Conversely, the LIHC based on total cost (€) focuses on large under-occupied properties. Thus, it does not adequately reflect the situation of low-income and large-families living in small properties.

4.3.2. Tenure type: living in private rented housing exacerbate the risk of fuel poverty

Based on the results of this study, tenure type was one of the most determinant factors in the odds of being in fuel poverty. Thus, families living in private rented properties are more than twice as likely to suffer from fuel poverty as owner occupied families. Household incomes are analyzed after deducting housing costs. Therefore, it is assumed that

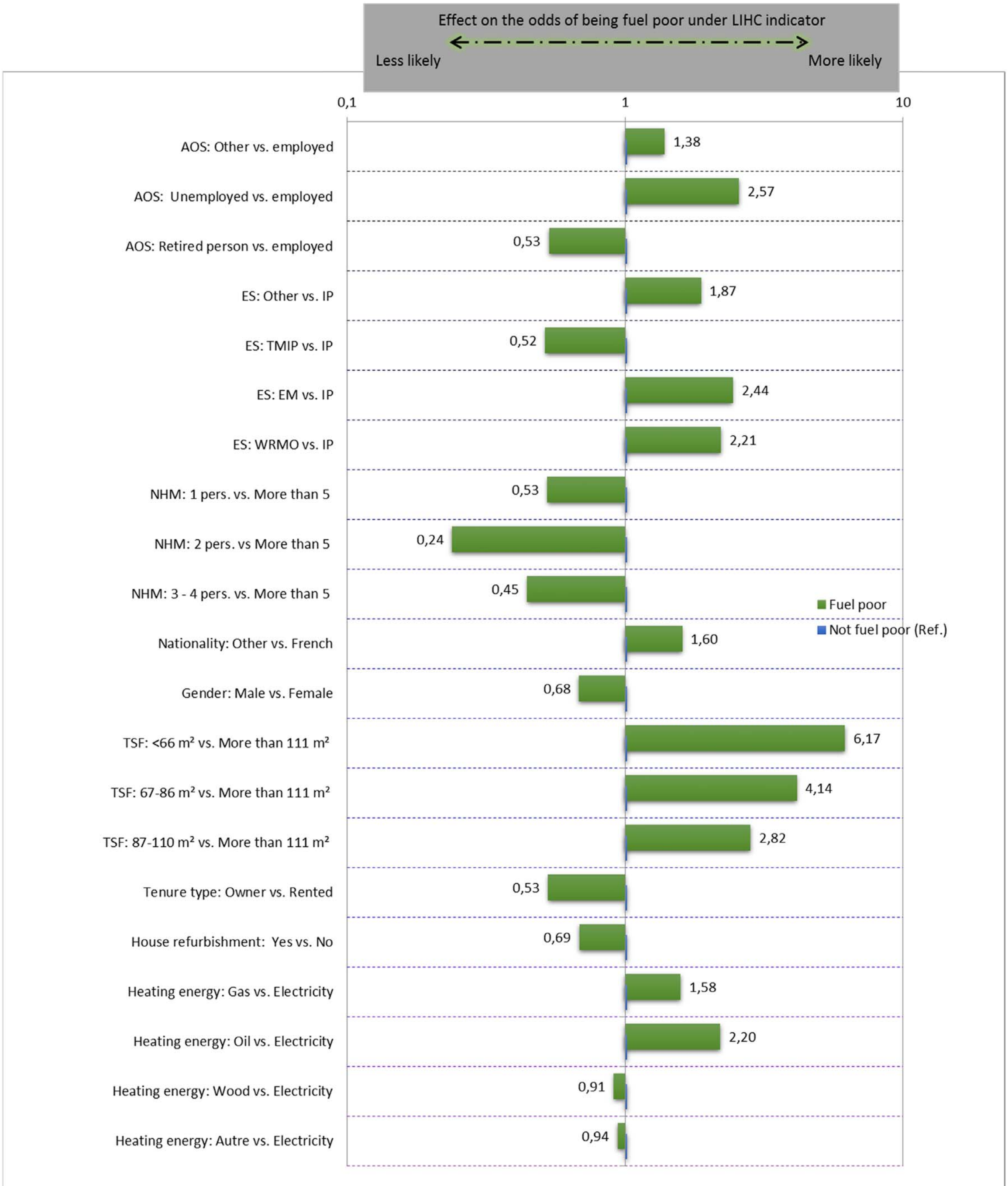

Fig. 7. Effect on the odds of being fuel poor under LIHC indicator. Note. Variables with an odds ratio greater than one imply an increased likelihood of household with that particular characteristics living in fuel poverty compared to the reference characteristics. Otherwise, an odds ratio less than one implies a reduced likelihood - holding all other characteristics constant and equal.

owner occupied households have a significantly higher disposal income than households living in rented accommodation. Our result is consistent with the findings of Legendre and Ricci (2015), which concluded that there is a strong relationship between being a homeowner and lower exposure to fuel precariousness. In addition, Masuma (2013) stated that families occupying privately rented house have over twice the odds of being fuel vulnerable than families living in social dwellings.

4.3.3. Actual occupation and employment status: Being unemployed, employees and workers households associated with higher exposure to fuel poverty.

Our findings suggest that employment status is key factor in explaining fuel poverty. Findings support that being unemployed increases the risk of fuel vulnerability more than two-fold compared to a HRP in some form of employment. This could be attributed to the fact that a large proportion of employed HRP have a higher income levels. In addition, employment status has a significant effect on the risk of being fuel poor. In fact, employees (odds ratio of 2.5) and workers (odds ratio of 2.2) are more likely to suffer from fuel vulnerability than intermediate profession HRP. In contrast, top managerial and intellectual professionals have about 50% lower risk of exposure to fuel poverty compared to intermediate professionals, all things being equal. Legendre and Ricci (2015) stated that highly educated HRP is associated with lower risk of exposure to fuel precariousness. Masuma (2013) concluded that unemployed or retired HRP increases the risk of exposure to fuel poverty. In addition, Healy and Clinch (2004) found that being a tenant and living in rent-free properties are positively associated with higher exposure to fuel poverty.

4.3.4. Race and ethnicity of household responsible person: Foreigners are the most vulnerable.

Regression results support that foreigners have a higher risk of exposure to fuel precariousness than the French (odds ratio of 1.6), all things being equal. Belaïd (2016) stated that HRP's ethnicity and race had a positive impact on French household energy demand. Bélaïd suggested that foreigners purchase energy on average more than the French does. However, we can assume that foreigner's homes are less energy-efficient, which makes it difficult or expensive to heat.

4.3.5. Total square footage of dwelling: Households living in small spaces have higher odds of exposure to fuel precariousness

The model reveals that dwelling size has a very important impact on the risk of being fuel poor. The risk of being fuel vulnerable increase significantly for small housing units. Families occupying houses with floor area of 66 m^2 (1st quartile) or less, have higher risk of being fuel vulnerable followed by those living in housing-units with floor size ranging from 67 to 86 m^2 (2nd quartile) and 87–110 m^2 (3rd quartile) with odds ratio of 6.2, 4 and 3 respectively. One explanation for these results is that home size is often correlated with income level. Masuma (2013) found that dwelling useable floor area has a substantial effect on the risk of being fuel poor. He stated that the risk of fuel vulnerability increases significantly for housing with floor size above 50 m^2. Masuma's approach used total rather than unit (£/m^2) energy costs threshold. Thus, this indicator focuses on high-size under-occupied housing-units and excludes many low-income families living in smaller properties of poor energy efficiency (Moore, 2012).

4.3.6. Heating energy: Families living in housing-units with individual electric heating system have reduced odds of being fuel poor

Heating energy shows a strong impact on the risk of fuel vulnerability. Living in a house with an electric heating system reduce which support the risk of fuel precariousness- around half the odds of families with heating system that use heating oil. In addition, the odds of exposure to fuel poverty are 58% higher for families that use gas-heating system compared to households using electric heating system. This could be attributed to the fact that dwellings with oil and gas heating system consume more energy than dwellings with electric heating system, often newer and more energy efficient. In fact, heating accounts for about 60% of all household energy bills. Therefore, high-efficiency heating systems can often cut household energy bills and reduce its exposure to fuel poverty. Legendre and Ricci (2015) stated that the heating system equipment is a key element that influence the odds of being fuel poor. They observed that using individual boiler is accompanied with a high risk of exposure to fuel precariousness. Finally, the findings ought to be treated with caution. The outcome may be related to the indicator selected to measure fuel poverty (LIHC). In fact, households using more efficient electrical devices may spend less money on energy, but probably cannot achieve the same level of thermal comfort at home with those using heating oil or gas. Nevertheless, fuel poverty is a complex to measure. This phenomenon is the product of a multiple factors, including low incomes, high energy costs, poor energy efficiency of the housing units and equipment (Moore, 2012; Thomson et al., 2016).

4.3.7. House refurbishment: Households living in renovated properties have reduced odds of being fuel poor.

House refurbishment can be another factor behind fuel poverty. Our model reveals that householders living in renovated properties have reduced odds of being fuel vulnerable than families living in non-renovated houses (odds ratio of 0.69). We expect that housing refurbishment is a key indicator of household domestic energy bill (energy costs). In fact, a renovated dwelling is associated with high-energy performance, which makes it easy and cheap to heat.

5. Conclusions and policy implications

The challenge of addressing fuel vulnerability and cold home-related negative health impacts is greatly important to improve the quality of life of many households by making their homes warmer and more efficient. Furthermore, reducing fuel poverty could substantially enhance health outcomes and reduce inequalities in health, as well as making an important contribution to tackling residential greenhouse emissions.

Focusing on France specifically, this research assesses the extent of fuel poverty and highlights how some factors influence exposure to fuel poverty. The empirical analysis is based on the LIHC indicator, which is a twin indicator consisting of the number of families that have both high energy bills and low incomes. It is based on cross-sectional survey data containing rich information about housing-units and occupant attributes.

The multivariate statistical analysis has identified four distinct energy poor household profiles to serve as a basis for targeted energy policy interventions tailored to specific socio-economic groups regarding fuel poverty alleviation. These are: (i) foreign family, employed, in shared building group (represents 24% of the sample); (ii) single person, retired, in small size flat group (accounts for 23% of the sample); (iii) family in individual house with gas and individual central heating system group (covers 32% of the sample); (iv) owner of high size rural house group (represents 21% of the sample). Therefore, it gives a detailed description of households' profile that suffer from fuel precariousness and informs the distinctive attributes of specific fuel poor families, including economic and housing conditions. This can shed light on the households that suffer from fuel poverty and provide ideas, which could help inform targeted fuel poverty-awareness campaigns. Nevertheless, this study does not intend to be exhaustive in cluster terms, but rather to offer indications on different ways of alleviating fuel poverty by targeting different household groups. Typologies are especially helpful in examining policy opportunities oriented towards specific household groups. This enables policy measures to be geared towards identifiable groups of population, particularly households that are in the deepest fuel poverty.

The used logistic regression model used explores the household and dwelling factors that are significant in driving a household to fuel precariousness. Results confirm the existence of social gradient in fuel precariousness, which supports the hypothesis that fuel poverty affects primarily the poorest households living in homes of poor energy efficiency.

Results of the model could be helpful in recognizing the most efficient interventions for fuel poverty reduction schemes. Besides the matter of enriching the energy policy debate, this study aims to contribute to the ongoing research on fuel poverty by providing a more elaborate overview on many facets of the fuel poverty phenomenon. It also highlights the need to upgrade the efficiency of the dwelling stock. This will not only improve the living conditions of households who are not able to afford to heat or cool their properties to comfortable levels but would also help to meet energy savings and carbon emissions reduction goals.

Behavioural habits and lifestyles are also drivers for the reduction of fuel poverty and its negative health effects. In fact, the findings provide a new outlook to the further studies. Therefore, examining new survey with more comprehensive data on household life style and energy use behavior may help to specify the nature of fuel poverty in more detail. In addition, richer sources of information can help to develop a comprehensive framework economically efficient policies to deliver reductions in fuel poverty. The ongoing literature on household energy demand is aware of the importance of household lifestyle and behaviors in shaping domestic energy consumption pattern. However, informing households about the importance of improving their housing energy efficiency and promoting energy-saving behaviors is vital to achieve optimum outcomes in terms of fuel poverty levels reduction.

Nevertheless, this research does not aim to be exhaustive in policy implications terms, but rather to provide some information on different ways of reducing fuel poverty, e.g. investing in the energy efficiency of the existing dwelling. This is a long-term sustainable manner of ensuring multiple outcomes, including health, social and environmental gains. In addition, addressing energy inefficient properties would have the strongest impact on the economy by stimulating the labor market.

Therefore, in order to achieve high levels of energy efficiency, government should implement a myriad of policies, including supportive measures to improve the energy efficiency of existing dwellings, sufficient flexibility within existing regulatory frameworks, measures to help occupants to improve energy efficiency of their housing units, energy ratings and certification schemes, information on financing options, etc.

Although the procedures used provide consistent results for the most part and even though the data used in this research is representative of French households, interpretations of the findings ought to be treated with caution. In fact, results and conclusions depend on the dataset quality and the approach used to assess the extent of fuel poverty. In theory, it is clear that the extent of the fuel poverty phenomenon depends on the definition and chosen measure.

Although the LIHC approach leaves a lot to be desired, in general, a “Low Income/High Cost” measure of fuel poverty has many advantages over the existing definition, particularly in its treatment of incomes.

This paper advocates for developing more ambitious strategies, including the development of new fuel poverty indicators and strategies to collect additional dedicated micro-data of fuel poverty. More comprehensive data on socio-economic factors related to domestic energy use and new dedicated survey of energy poverty would help to comprehensively untangle the complexity of energy poverty phenomenon. Thomson et al. (2017) highlighted that the scarcity of suitable data at the EU level is limiting the measures that can be applied universally as well as preventing rigorous assessment of energy poverty across the EU.

Nevertheless, in order to advance the measurement of fuel poverty, the approach used to assess the extent of fuel poverty has to improve in order to combine the information on different aspects of fuel poverty. A recent review-based study conducted by Tirado Herrero (2017) on the risks of not critically elaborating and reporting energy poverty statistics argued against official, single-indicator energy poverty metrics like the UK's LIHC and pleaded for multiple-indicator approaches that explicitly acknowledge the shortcomings of each of the methods implemented.

Finally, it is worth emphasizing that fuel precariousness is a multifaceted and complex issue, which requires proactive schemes to anticipate its evolution patterns and alleviate its tangible impacts on people's health and well-being over the next few years.

References

Abdelmalek, A.A., Zakaria, E., Michel, S., 2010. Evaluation of text clustering methods using WordNet. Int. Arab J. Inf. Technol. 7 (4), 349–356.

Aktürk, D., Gün, S., Kumuk, T., 2007. Multiple correspondence analysis technique used in analyzing the categorical data in social sciences. J. Appl. Sci. 7 (4), 585–588.

Bair, S., Belaïd, F., Teissier, O., 2017. Quantifier et caractériser les ménages en précarité énergétique. La Revue du CGDD, Théma, N° 1, 2017.

Belaïd, F., 2017. Untangling the complexity of the direct and indirect determinants of the residential energy consumption in France: quantitative analysis using a structural equation modeling approach. Energy Policy 110, 246–256.

Belaïd, F., 2016. Understanding the spectrum of domestic energy consumption: empirical evidence from France. Energy Policy 92, 220–233.

Belaid, F., Garcia, T., 2016. Understanding the spectrum of residential energy-saving behaviours: french evidence using disaggregated data. Energy Econ. 57, 204–214.

Boardman, B., Hunt, S., 1994. Domestic Energy and Affordable Warmth (Report no. 30). The Watt Committee on Energy, London (1994).

Boardman, B., 1991. Fuel Poverty: from Cold Homes to Affordable Warmth. Belhaven Press, London.

Boardman, B., 2012. Fuel poverty synthesis: lessons learnt, actions needed. Energy Policy 49, 143–148.

Boardman, B., Bullock, S., McLaren, D., 1999. Equity and the Environment. Catalyst Trust, London.

Bouzarovski, S., Petrova, S., 2015. A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. Energy Res. Social. Sci. 10, 31–40.

Bouzarovski, S., Tirado Herrero, S., 2017. The energy divide: integrating energy transitions, regional inequalities and poverty trends in the European Union. Eur. Urban Reg. Stud. 24 (1), 69–86.

Bouzarovski, S., Petrova, S., Sarlamanov, R., 2012. Energy poverty policies in the EU: a critical perspective. Energy Policy 49, 76–82.

BPIE (Buildings Performance Institute Europe), 2014. Alleviating Fuel poverty in the EU. Investing in Home renovation, a sustainable and inclusive solution. BPIE, Brussels.

Bradshaw, J., Hutton, S., 1983. Social policy options and fuel poverty. J. Econ. Psychol. 3 (3–4), 249–266.

Buzar, S., 2007. Energy Poverty in Eastern Europe: hidden Geographies of Deprivation. Ashgate, Farnham, UK.

EPEE, 2009. Tackling fuel poverty in Europe. 〈https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/epee_european_fuel_poverty_and_energy_ef ficiency_en.pdf〉.

European Economic and Social Committee (EESC), 2013. Opinion of the European Economic and Social Committee on “For Coordinated European Measures to Prevent and Combat Energy Poverty” (Own-Initiative Opinion). EESC, Brussels.

Gardner, I.A., Greiner, M., 2006. Receiver-operating characteristic curves and likelihood ratios: improvements over traditional methods for the evaluation and application of veterinary clinical pathology tests. Vet. Clin. Pathol. 35 (1), 8–17.

Healy, J.D., 2001. Home Sweet Home? Assessing Housing Conditions and Fuel Poverty in Europe. University College Dublin, Department of Environmental Studies.

Healy, J.D., Clinch, J.P., 2004. 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 (2), 207–220.

Hills, J., 2011. Fuel Poverty: The Problem and its Measurement. CASE Report, 69. Department for Energy and Climate Change, London, UK.

Hills, J., 2012. Getting the Measure of Fuel Poverty, Final Report of the Fuel Poverty Review CASE report 72.

Hosmer, D.W., Lemeshow, S., 2000. Interpretation of the fitted logistic regression model. Appl. Logist. Regres. 47–90 (Second Edition).

Hosmer Jr, D.W., Lemeshow, S., 2004. Applied Logistic Regression. John Wiley & Sons.

Howden-Chapman, P., Viggers, H., Chapman, R., O'Sullivan, K., Barnard, L.T., Lloyd, B., 2012. Tackling cold housing and fuel poverty in New Zealand: a review of policies, research, and health impacts. Energy Policy 49, 134–142.

Imbert, I., Nogues, P., Sevenet, M., 2016. Same but different: on the applicability of fuel poverty indicators across countries—insights from France. Energy Res. Social. Sci. 15, 75–85.

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

Lévy, J.P., Belaïd, F., 2018. The determinants of domestic energy consumption in France: energy modes, habitat, households and life cycles. Renew. Sustain. Energy Rev. 81 (2), 2104–2114.

Lévy, J.P., Roudil, N., Flamand, A., Belaïd, F., 2014. Les déterminants de la consommation énergétique domestique. Flux 2, 40–54.

Lewis, P., 1982. Fuel poverty can be stopped. National Right to Fuel Campaign.

Liddell, C., Morris, C., 2010. Fuel poverty and human health: a review of recent evidence. Energy Policy 38 (6), 2987–2997.

Liddell, C., Morris, C., McKenzie, S.J.P., Rae, G., 2012. Measuring and monitoring fuel poverty in the UK: national and regional perspectives. Energy Policy 49, 27–32.

Macours, K., Swinnen, J.F.M., 2008. Rural–urban poverty differences in transition countries. World Dev. 36 (11), 2170–2187.

Masuma, A., 2013. Modelling the likelihood of being fuel poor. Department of Energy & Climate Change.

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

Pachauri, S., Spreng, D., 2011. Measuring and monitoring energy poverty. Energy Policy 39 (12), 7497–7504.

Papada, L., Kaliampakos, D., 2016. Measuring energy poverty in Greece. Energy Policy 94, 157–165.

Richardson, P., 1978. Fuel Poverty: A Study of Fuel Poverty among Low Income Council Tenants. Department of Social Administration and Social Work, University of York.

Shortt, N., Rugkåsa, J., 2007. “The walls were so damp and cold” fuel poverty and ill health in Northern Ireland: results from a housing intervention. Health Place 13 (1), 99–110.

Sovacool, B.K., 2015. Fuel poverty, affordability, and energy justice in England: policy insights from the Warm Front Program. Energy 93, 361–371.

Sovacool, B.K., Dworkin, M.H., 2015. Energy justice: conceptual insights and practical applications. Appl. Energy 142, 435–444.

Teller-Elsberg, J., Sovacool, B., Smith, T., Laine, E., 2016. Fuel poverty, excess winter deaths, and energy costs in Vermont: burdensome for whom? Energy Policy 90, 81–91.

Thomson, H., Bouzarovski, S., Snell, C., 2017. Rethinking the measurement of energy poverty in Europe: a critical analysis of indicators and data. Indoor Built Environ. 26 (7), 879–901.
Thomson, H., Snell, C., Liddell, C., 2016. Fuel poverty in the European Union: a concept in need of definition? People, Place Policy Spec. Issue Int. Perspect. fuel Poverty 10, 5–24.
Thomson, H., Snell, C., 2013. Quantifying the prevalence of fuel poverty across the European Union. Energy Policy 52, 563–572.
Tirado Herrero, S., 2017. Energy poverty indicators: a critical review of methods. Indoor Built Environ. 26 (7), 1018–1031.
Walker, G., Day, R., 2012. Fuel poverty as injustice: integrating distribution, recognition and procedure in the struggle for affordable warmth. Energy Policy 49, 69–75.
Ward, J.H., 1963. Hierarchical grouping to optimize an objective function. J. Am. Stat. Assoc. 58, 236–244.
WEO, 2015. Electricity Access Database. World Energy Outlook, OECD/IEA 2015.
Wilkinson, P., Smith, K.R., Joffe, M., Haines, A., 2007. A global perspective on energy: health effects and injustices. Lancet 370, 965–978.