IAPE '19, Oxford, United Kingdom
ISBN: 978-1-912532-05-6

Measuring fuel poverty in Italy: application of different fuel-poverty criteria to a national household segmentation

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ABSTRACT
Fuel poverty is a multidisciplinary topic, coupling the demand-side to the supply-side, and the "*household-scale*" to the "*country-scale*". In this complex framework, this paper contributes to the present-day discussion regarding suitable indicators to quantify fuel poverty, focusing on the Italian case study. In particular, we have compared different indicators taken from the literature and we have further developed a novel indicator based on the "*minimum thermal comfort*" constrain. The different indicators have been applied to the "*household Budget Survey*" nationally representative survey and the results have been presented, on an aggregated point of view, by using the segmentation of the Italian households previously proposed by the authors. Thus, the proposed assessment of the fuel poverty couples the "*household-scale*" to the "*country-scale*", in the process of identifying vulnerable households: for this reason, this paper is able to scale-up the "*household-scale*" to consider the whole "*country-scale*". In summary, this work contributes to the broader framework of "*the human dimensions of energy use*". The obtained results are of practical importance and provide a rational basis for policy makers when planning strategies to tackle the incidence of fuel poverty in Italy.

Keywords
Energy expenditure; Residential sector; Socio-demographics; Energy use and consumption; Fuel poverty.

1. INTRODUCTION
In the early 1991, Brenda Boardman published the book "*Fuel poverty: from cold homes to affordable warmth*" [1]. This publication is widely recognized as a milestone in the current research activities as it started the research studies regarding the "*energy poverty*" and "*fuel poverty*" concepts. Since 1991, many studied have been devoted to the "*energy poverty*" and "*fuel poverty*" concepts, as these situations determine a poor quality of life and might affect health conditions. Before proceeding further with the introduction, it should be noted that important differences between "*energy poverty*" and "*fuel poverty*" concepts exist [2] and they should be clarified a-priori. Both concepts involve the energy consumption at the "*household-scale*" in the residential sector; on one hand, the "*energy poverty*" concept regards the issues of energy access, on the other hand, the "*fuel poverty*" concept regards the issues of heating homes in relatively wealthy countries. As in this paper we focuses on the Italian case, we need to refer to the "*fuel poverty*" concept. It is important to observe that this study only relates to the use of energy for heating purposes, accordingly with the typical research framework on fuel poverty.

As anticipated, since 1991, an increasing number of papers has been published concerning this topic: a well-known example of the current state-of-the-art is the special issue introduced by Liddell's editorial [3]. Unfortunately, despite the ongoing studies, three main issues are still far from being solved [2-5]: the correct definition of "*energy/fuel poverty*", the formulation of suitable indicators to measure "*energy/fuel poverty*", and the formulation of shared strategies to tackle the incidence of "*energy/fuel poverty*". The formulation of suitable strategies will not be covered in this paper and, as far as the definition of "*energy/fuel poverty*" is concerned, we will follows the definition of "*fuel poverty*" proposed by the European Observatory on Energy Poverty [6] and we will not go into this discussion: "*Energy poverty occurs when a household suffers from a lack of adequate energy services in the home*". Conversely, this paper contributes to the existing discussion regarding suitable indicators: to the authors' opinion, "*fuel poverty*" indicators need to be based on the "*household-scale*" and, subsequently, need to be scaled-up to consider the whole "*country-scale*". In the scaling-up process from the "*household-scale*" toward the "*country-scale*", the geographical dimension of "*energy/fuel poverty*" and its relationship with the socio-demographic dimension, need to be considered. This multi-scale approach is considered, within this paper, by applying different indicators of fuel poverty to a household segmentation based on a nationally representative survey. In particular, we have compared different indicators taken from the literature, and we have further developed a novel indicator based on the "*minimum thermal comfort*" constrain [7]. This indicator is supposed to overcome the limitation of the generally applied approaches as discussed in refs. [8-9]: the income-based approach, the minimum-income-standard approach, the low-income/high-cost approach. The minimum thermal comfort-constrain indicator compares, for the different households, the minimum energy expenditure (to reach a minimum level of comfort conditions) with the annual real energy expenditure. The former represents the theoretical household thermal requirement (for heating purposes) and is obtained by applying a lumped parameter model to the whole Italian building stock; conversely, the latter is based on data available on the nationally representative survey, the "h*ousehold Budget Survey*", performed by the Italian National Institute of Statistics [10]). Thus, the "*minimum thermal comfort*" constrain indicator couples the demand-side and the supply-side.

The different indicators are applied to the nationally representative survey, the "h*ousehold Budget Survey*" [10] and the results are presented on an aggregated point of view, by using the segmentation of the Italian households proposed by Besagni et al. [12]. It should be noted that the proposed assessment of the fuel

DOI: http://dx.doi.org/10.17501.......................................

poverty couples the "*household-scale*" to the "*country-scale*", by using the nationally representative survey. For this reason, this paper is able to scale-up the "*household-scale*" to consider the whole "*country-scale*".

In summary, this paper contributes to the existing discussion regarding the incidence of fuel poverty in Italy and might serve as basis for policymakers when planning investments aiming to tackle the incidence of fuel poverty, by taking into account the many changes that characterize the "*household-scale*". This paper proceeds as follows. Section 2 describes the approach, while Section 3 discusses the results. Finally, the main outcomes and outlooks are presented and discussed.

2. RESEARCH DESIGN AND METHODS

2.1 Dataset and household segmentation

We have used the "*Household Budget Survey: microdata for research purposes*" (year 2015, ref. [10]). This dataset was obtained by Italian National Institute of Statistics (*ISTAT*) and it is representative of the whole Italian population. The data were collected from 15015 households, in 502 different municipalities; for each household more than 1264 variables are available and concerns socio-demographic information, dwelling characteristics, appliances and monthly expenditures. In our previous study [11] we have used different statistical methods to determine the relationship between the energy expenditure and the household variables and, subsequently, to provide a segmentation of the Italian families, by using a segmentation-tree approach. In this paper we use the outcome of the household segmentation (concerning the total per-capital annual energy expenditure) obtained in our previous paper. This household segmentation is displayed in Figure 1 and the classification is based on the following variables (listed in Table 1): household structures (2 splits), geographic area (3 splits), the heating type and system, (2 splits) the floor surface (2 splits) and the dwelling type (2 splits).

Table 1. Code names of the variables in Figure 1 with their summary statistics

Variable	Summary statistics**
Household structure*	(a) Single person 18-34 years [391], (b) Single person 35-64 years [1817], (c) Single person 65 years and more [2240], (d) Couple without children with *HRP* 18-34 years [178], (e) Couple without children with *HRP* 35-64 years [1350], (f) Couple without children with *HRP* 65 years and more [2164], (g) Couple with 1 child [2276], (h) Couple with 2 children [2184], (i) Couple with 3 children or more [495], (l) Mono parent family [1033], (m) Others [885]
Geographic location	(a) North-west [3284], (b) North-east [3382], (c) Centre [2791], (d) South [4385], (e) Sicily [753], (f) Sardinia [418]
Type of dwelling	(a) Single family villa [2738], (b) Multifamily villa [4587], (c) Apartments in building with less than 10 apartments [3733], (d) Apartments in building with 10 or more apartments [3939], (e) Other [16]
Floor area	Continuous variable [Mean = 98 / Variance = 1342]

** HRP = Household Representative Person, which is the individual that is taken to represent the household. In this study, it describes the highest income earner in the household.*
*** Summary statistics evaluated on the whole data-set*

In Figure 1 it is observed that the first, and most important, splitting is based on the household structure and the splitting divide between "*single-person-based households*" and "*non-single-person-based households*"; subsequently, the geographical dimension and the dwelling characteristics are used. It is worth noting that, in the segmentation tree, socio-demographic and building variables have been used; conversely, no appliance variables have been applied; this result suggest that, despite appliance variables are important in determining higher energy expenditures comparing the different households, they cannot be used to select homogeneous groups of households.

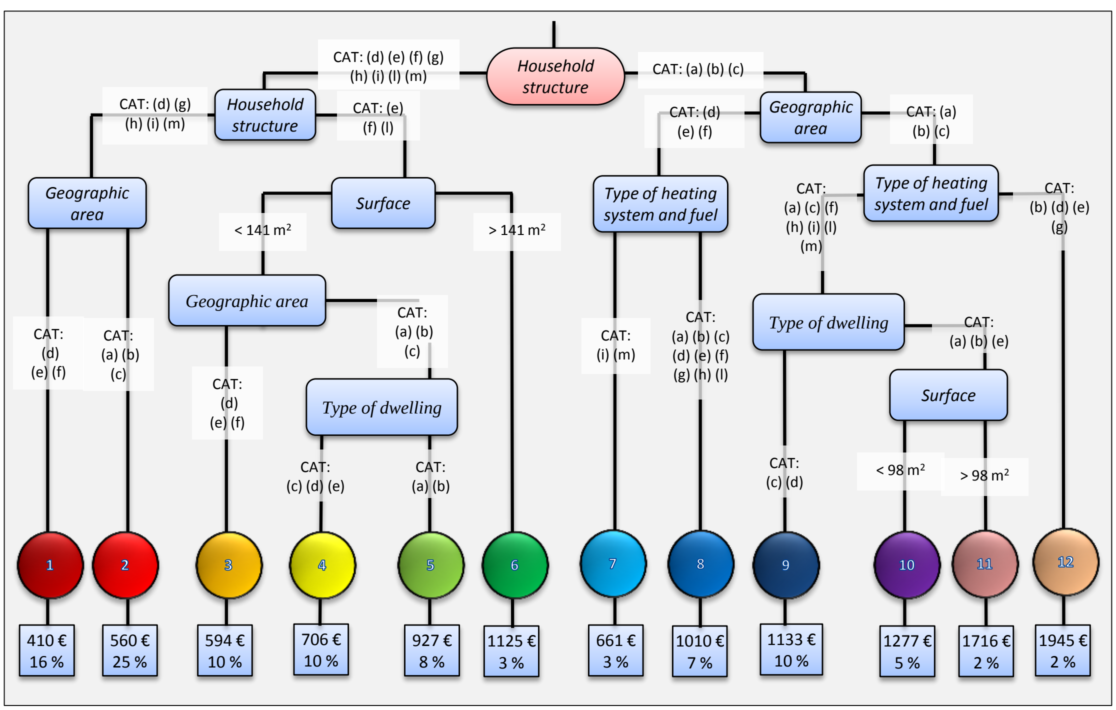

Figure 1. Household segmentation (total per-capital annual energy expenditure) obtained by Besagni and Borgarello [11] – Code names of the splitting are listed in Table 1

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2.2 Measures of fuel poverty

In order to contribute to the existing discussion on suitable indicators to quantify the incidence of fuel poverty at the "*country-scale*" in Italy, we have applied eight different indicators to the data available in the *"Household Budget Survey: microdata for research purposes*" and, subsequently, we have presented the outcomes of the results based on the household segmentation proposed in Figure 1. In particular, we have used seven indicators taken from the literature (#1-#7, in the following) and we have further developed a novel indicator (#8, in the following) based on the minimum thermal comfort-constrain:

- Criterion#1. Energy expenditure is lower than half of the median [12];
- Criterion#2. Incidence of energy expenditure on the total household expenditure is higher than double of the median [12];
- Criterion#3. Condition of absolute poverty: this criterion has been used as, in the dataset, we have not information concerning the income of the households in order to apply the income-based criteria;
- Criterion#4. Energy expenditure is higher than double of the median [13];
- Criterion#5. Energy expenditure is higher compared with food expenditure [13];
- Criterion#6. Household having scarce economic resource – this criterion has been used as, in the dataset, we have not information concerning the income of the households in order to apply the income-based criteria;
- Criterion#7. Household having insufficient economic resource – this criterion has been used as, in the dataset, we have not information concerning the income of the households in order to apply the income-based criteria.
- Criterion#8. Households having thermal energy expenditure below the limit to reach a minimum comfort condition [7]. It is worth noting that this indicator considers the thermal energy expenditure for heating purposes. It neglects the situation where there are households with a significant cooling load (i.e., some regions in the Mediterranean area). The inclusion of the cooling load within fuel poverty definition has not been considered so far to the authors' knowledge, but would be a promising step forward with the respect to the present body of knowledge and an interesting point of view for future studies. This criterion is further discussed in the following sections.

2.3 "*Minimum thermal comfort-constrain*" criterion: details and implementation

The "*minimum thermal comfort*" criterion is developed by integrating different modeling approaches with the available dataset in a four-steps procedure. In step#1, a lumped parameter model, is applied to compute the annual "*baseline thermal energy requirement*" for different household types. In step#2, the obtained "*baseline thermal energy requirement*" is converted into the "*minimal thermal energy requirement*" (related to comfort-based). In step#3, the "*minimal thermal energy requirement*" is converted into the "*minimal thermal energy expenditure*". Finally, in step#4 the data provided in the "h*ousehold Budget Survey: microdata for research*", are post-processed to compute the annual "*real thermal energy expenditure*". At this point, the annual "*real thermal energy expenditure*" is compared with the "*minimal thermal energy expenditure*", to evaluate the fuel-poor households. An advantage of the "*minimum thermal comfort*" measure is that it does not need to assess the condition of energy vulnerability based on a-priori thresholds, but the minimum thermal comfort is defined according to the specific properties of each dwelling, i.e., period of construction of the dwelling, region of residence, number of members of the family,…

2.3.1 Step#1. Baseline thermal energy requirement

The lumped parameter model described within UNI-EN-ISO 13790:2008 [14]—based on the simple hourly method with hourly time discretization—allows computing the annual heating requirements ($F_{Baseline}$). Capozza et al. [15] and, later, Ballarini et al. [16] applied this model to compute the annual baseline household heating requirements ($F_{Baseline,Capozza}$ - Table 15 proposed in ref. [15]) for 140 residential buildings, representative of the Italian building stock, classified in terms of dwelling type, construction period and climatic zone, and defined as follows:

- dwelling type: (a) single-family house (*B1*), (b) terraced house (*B2*), (c) multi-family house (*B3*) and (d) apartment block (*B4*);
- construction period: (a) ante-1920 (*V1*), (b) 1921–1945 (*V2*), (c) 1946–1960 (*V3*), (d) 1961–1975 (*V4*), (e) 1976–1990 (*V5*), (f) 1991–2005 (*V6*), (g) 2005 -ongoing (*V7*);
- climatic zone, classified based on the heating degree-days (*HDD)*, as reported in the Italian regulation [17] (Figure 2): (a) zone "*B*" (600 < *HDD* ≤ 900); (b) zone "*C*" (900 < *HDD* ≤ 1400); (c) zone "*D*" (1400 < *HDD* ≤ 2100); (d) zone "*E*" (2100 < *HDD* ≤ 3000); (e) zone "*F*" (*HDD* > 3000). Zone "*A*" (≤ 600 HDD) has not been considered as it is not representative (only two Italian municipalities are located in climatic zone). The heating period, for the different climatic zones, and the number of hours when the heating system was turned on, are selected based on the current regulations in Italy [31].

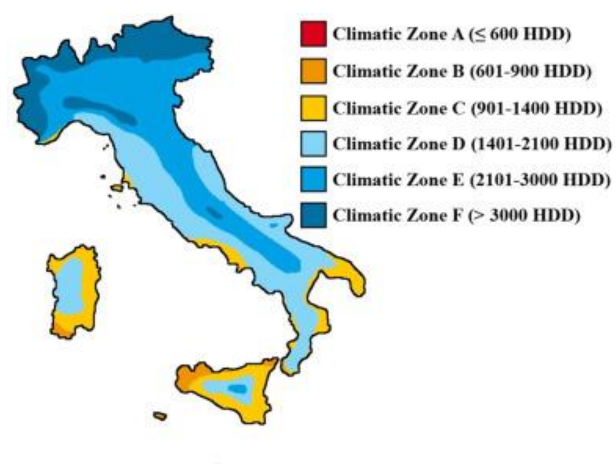

Figure 2. Climatic regions in Italy, ref. [16]

The above-mentioned 140 dwelling types are characterized by different thermophysical properties (i.e., thermal transmission coefficients of the glazed and opaque building components,

DOI: http://dx.doi.org/10.17501..

geometrical details, …); these input data are listed in ref. [15].ì and are available upon request The meteorological data, for the different zones, have been implemented based on ref. [19].

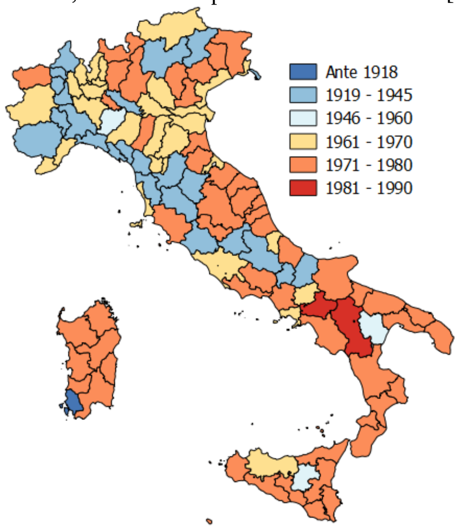

Figure 3. Period of construction of buildings in Italy

The annual baseline household heating requirements computed by Capozza et al. [15] refer to the 2006; conversely, the "*Household Budget Survey*" considers the 2015 situation. For this reason, a calibration procedure is needed and, in particular, Faiella et al. [7] suggested a calibration based on the overall Italian energy consumption (C_{2006}=29.54 Mtep and C_{2015}=23.73 Mtep). The household heating requirements computed by Capozza et al. [15] are corrected as in Eq. (1):

$$F_{Baseline,Capozza,2015}=\frac{F_{Baseline,Capozza}\ C_{2015}}{C_{2006}} \quad (1)$$

It is worth nothing that the data used by Capozza et al. [15] to classify the dwelling types in the the "1 cannot be coupled as-is with the *Household Budget Survey*" dataset (see the tables provided in the paper of Besagni and Borgarello [11]): in order to assign a heating requirement to every household in the dataset, the variables selected by Capozza et al. [15] and the variables in the "*Household Budget Survey*" dataset need to be matched. To this end, the following criteria have been applied:

- construction period. V1 is matched with "Before 1900"; V2 is matched with "Between 1900 and 1949"; V3 is matched with "Between 1950 and 1959"; V4 is matched with "Between 1960 and 1969" and "Between 1970 and 1979"; V5 is matched with "Between 1980 and 1989"; V6 is matched with "Between 1990 and 1999"; V7 is matched with "Between 2000 and 2009" and "After 2009";
- dwelling type. B1 is matched with "Single family villa"; B2 is matched with "Multifamily villa"; B3 is matched with "Apartments in building with less than 10 apartments" and "other"; B4 is matched with "Apartments in building with 10 or more apartments";
- geographic region. The geographic locations employed by Capozza et al. [15] concern the above-mentioned climatic zones; conversely, in the dataset, the different regions are used (and, they are subsequently grouped in macro-regions, see data in ref. [11]). As the climatic zones are based on *HDDs*, the annual baseline household heating requirement for the different regions ($F_{Baseline,2015,region_k}$), have been computed by a weighted average based on the extension of the climatic bands inside the different regions. The extension of the climatic areas is approximated by counting the number of municipalities (nm), in each region, corresponding to the different climatic zones:

$$F_{Baseline,2015,region_k}=\frac{\sum_{j=1}^{5} F_{Baseline,Capozza,2015,j}\cdot nm_{k,j}}{\sum_{j=1}^{5} nm_{k,j}} \quad (2)$$

In Eq. (2) *j* is the *j*-climatic area and *k* is the *k*-region.

2.3.2 Step#2. Minimum thermal energy requirement

In the previous section, the baselined thermal energy requirements have been obtained. These data should be converted into minimum thermal energy requirements. The conversion from baseline to minimum thermal energy requirement is needed, as the aim of this paper is to identity vulnerable conditions in the Italian case study. The first correction is related to the crowding effects: a study performed by RSE [20] shows that, to account for the influence of the number of occupants and the size of the building on energy consumption for heating purposes, the correction defined in Eq. (3) should be applied:

$$F_{Baseline,2015,region_k,IA}= F_{Baseline,2015,region_k}\left[1+\alpha\left(\frac{IA_{eff}-IA_{std}}{IA_{std}}\right)\right] \quad (3)$$

In, Eq. (3), α = -0.06 and the heat requirement corrected for the crowding effect (the left side of Eq. (3)), may either increase or decrease as a function of the coefficients IA_{eff} (related to the household variables) and IA_{std} (standard and constant values). These parameters depends on the number of occupants, depending on the number of family members ($N_{occupants}$) and the surface of the dwelling ($A_{dwelling}$):.

$$IA_{eff}=\frac{N_{occupants}}{A_{dwelling}} \quad (4)$$

$$IA_{std}=\frac{N_{occupants,standard-value}}{A_{dwelling,standard-value}}=\frac{1}{40} \quad (5)$$

The second correction is related to the comfort conditions (*CC*) inside the households effects: The expected levels of comfort are defined by the European standard EN 15251 [21] and are divided into 3 categories; operating temperatures ($T_{Op,eff}$) are associated to each of these categories [20], as follows:

- CC1: high comfort conditions → $T_{Op,Eff}$=20.5°C
- CC2: normal comfort conditions → $T_{Op,Eff}$=18.6°C
- CC3: low comfort conditions → $T_{Op,Eff}$=17.5°C

In agreement with Faiella et al. [7], the *CC3* conditions are selected. Thus, the outcome of Eq. (3) is further corrected by using Eq. (6):

$$F_{Baseline,2015,region_k,MIN}= F_{Baseline,2015,region_k,IA}\left[1+\gamma\left(T_{Op,Eff}-T_{Op,STD}\right)\right] \quad (6)$$

In Eq. (6), $T_{Op,eff}$ is the standard operating temperature from, equal to 20 ° C, while γ = 0.13 [1/ ° C]. This procedure is applied to all the households in the dataset; the comparison between the baseline thermal energy requirement and the minimum thermal energy requirement is displayed in Figure 4.

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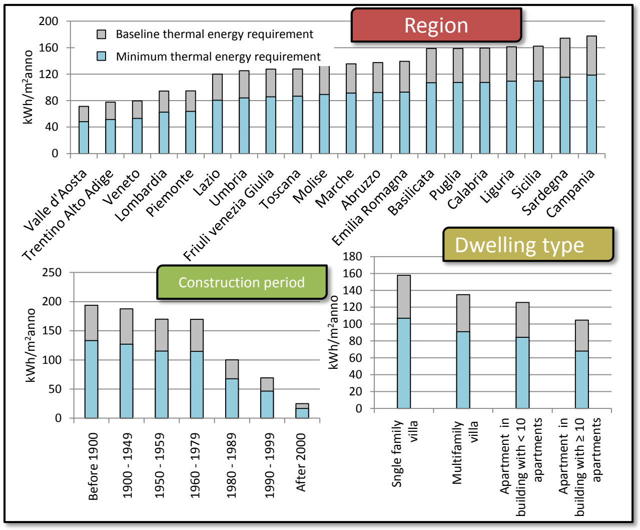

Figure 4. Comparison between the baseline and the minimum thermal energy requirements.

In Figure 4, it is observed how the heating requirements reduce in terms of average category; in particular Figure 4 presents the results in terms of construction, the dwelling type and geographic region. Finally, the minimum heating requirements per unit-area can be assigned to the different households in the dataset by multiplying their value for the household floor area:

$$F_{Baseline,2015,region_k,MIN,S} = F_{Baseline,2015,region_k,MIN} \times A_{dwelling} \quad (7)$$

2.3.3 Step#3. Minimum thermal energy expenditure

In the "*Household Budget Survey*" dataset, expenditure data are available; thus, the heating requirements should be converted into heating expenditures. To this end, the data obtained in Eq. (7) for every household have been converted into equivalent standard cubic meters of natural gas (*NG*) as follows:

$$NG = F_{Baseline,2015,region_k,MIN,S}\,\omega_{GN} \quad (9)$$

In Eq. (9) $\omega_{GN}=0.914\,[\mathrm{Sm^3/kWh}]$ (reference technology: convectional boiler); in practical applications, ω_{GN} might depends on the type of energy conversion system, the altitude of the municipality, the climate zone and the number of days of operation of the heating system. Finally, the equivalent standard cubic meters of natural gas are converted into thermal expenditure by using the structure of cost of natural gas in the reference year 2015 [22], thus obtaining $S_{Comfort,MIN,i}$. In this procedure, the costs for Sardinia were supposed equal as the ones for Sicily, for an estimate. The hypothesis underlying Eq. (9) is that the heat requirement is completely satisfied by using natural gas; this assumption is supported by the fact that, in Italy, the main source of energy for the heating of the home and water is gas, used by > 70% of all households (with some exceptions, as for example in Sardinia). Future study would improve this estimate by considering the different sources of thermal energy

2.3.4 Step#4. Real thermal energy expenditure

In the "*Household Budget Survey*" dataset, expenditures are provided in terms of monthly data (viz., every record in the dataset refer to a precise month during the year). In particular, the monthly heating energy expenditure (have been obtained by summing the following components: (a) gas from network, (b) central heating, (c) district heating, (d) liquid gases, (e) liquid fuels, (f) coal, (g) solid fuels; however, as stated above, in Italy, the main source of energy for the heating of the home and water is gas and, thus, the comparison with the outcome of Eq. (8), can be considered as a first approximation, can be considered acceptance (i.e., electric-based heating systems are not largely used). It is known that the demand side determining the heating/cooling loads in buildings consists of household/attitude contribution and an ambient contribution. The former is intrinsically present in the statistical dataset; conversely, the latter has been discussed by Besagni and Boregarello [11]. In particular, in our previous study, we proposed a method to convert the monthly energy expenditures into annual energy expenditures and, (See Appendix A of ref. [37]; the same procedure has been applied in this paper and, in conclusion, $S_{Real,i}$ are obtained.

2.3.5 Step#4. Measure of fuel poverty

Based on the outcome of Section 2.3.3 (the minimum thermal energy expenditure for each i-household, $S_{Comfort,MIN,i}$) and the outcome of Section 2.3.4 (the real thermal energy expenditure, $S_{Real,I}$), the criterion#8 to estimate the incidence of fuel poverty (as listed in Section 2.2) is computed as follows, for the i-household:

$$\frac{S_{ComfortMIN_i} - S_{Ris.Ann_i}}{S_{ComfortMIN_i}} > 25\% \quad (10)$$

Eq. (10) identify, as fuel poor household, the ones that are unable to satisfy three quarters of the minimum annual expenditure necessary to achieve acceptable minimum thermal comfort.

3. RESULTS AND DISCUSSION

In this section, the eight fuel poverty indicators, discussed in Sections 2.2 – 2.3, are applied to the household segmentation presented in Figure 1; the results of this analysis are displayed in Table 2 and in Figure 5. The former displays the percentage of families satisfying the different conditions within each cluster. Conversely, the latter displays the distribution inside each cluster of the different indicators (please note that the last approach is sensitive to the number of households in the different clusters).

Table 2. Percentage of families that inside a cluster satisfy the specific condition 1 – Values in percentage – Colorbar as follows: (a) red color, maximum; (b) green color, minimum

	Indicator							
Cluster	#1	#2	#3	#4	#5	#6	#7	#8
1	39.7	10.0	8.2	1.2	2.9	40.9	10.6	19.0
2	21.2	9.8	5.8	2.3	4.2	34.7	5.8	23.0
3	16.2	17.2	8.0	3.1	4.6	42.0	10.2	27.2
4	13.2	10.1	2.3	5.7	4.7	35.2	5.3	27.3
5	4.5	19.4	2.0	11.0	6.6	32.6	4.5	26.2
6	3.4	15.2	1.3	20.4	7.6	21.5	4.2	41.5
7	16.2	13.0	10.1	4.3	6.5	53.0	18.2	44.7
8	4.2	24.2	5.2	13.4	10.7	46.5	8.8	34.2
9	5.4	13.9	3.9	17.9	9.9	36.5	7.3	33.2
10	2.1	25.2	5.0	27.0	10.6	39.7	5.9	33.8
11	2.0	22.1	1.1	45.1	17.0	33.0	4.3	43.0
12	5.8	31.9	0.9	50.9	22.6	34.5	11.1	20.8

** Refer to Figure 1 for the cluster classification within the national household segmentation*

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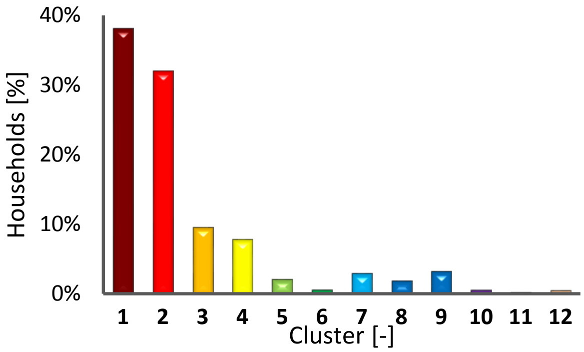
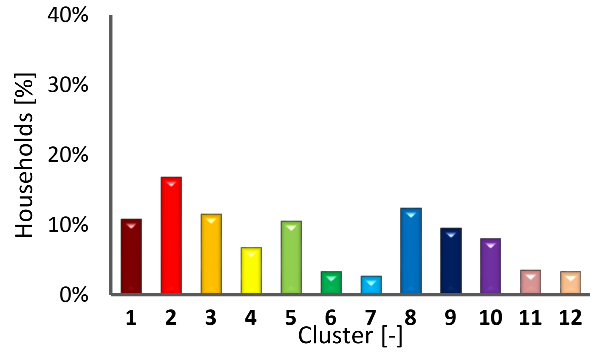
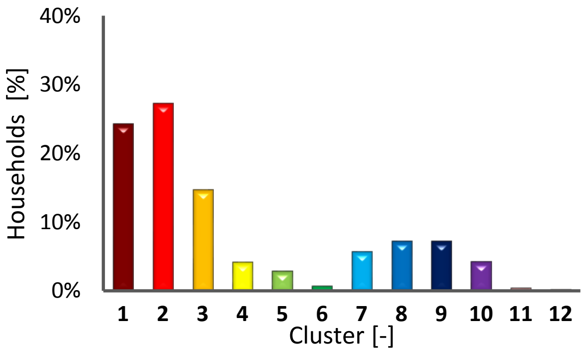


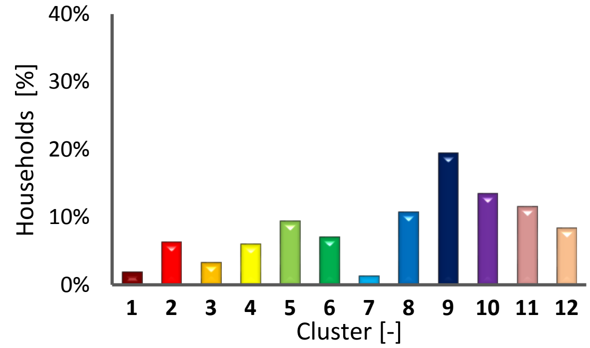
(a) Criterion#1



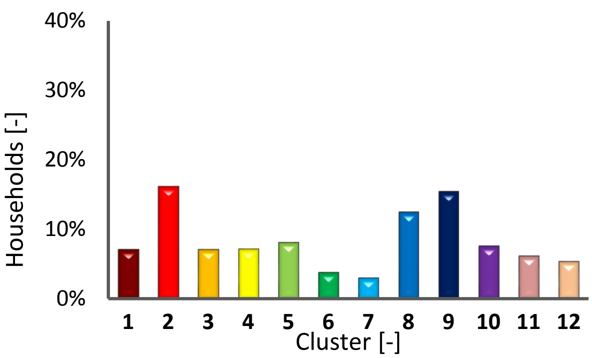
(b) Criterion#2



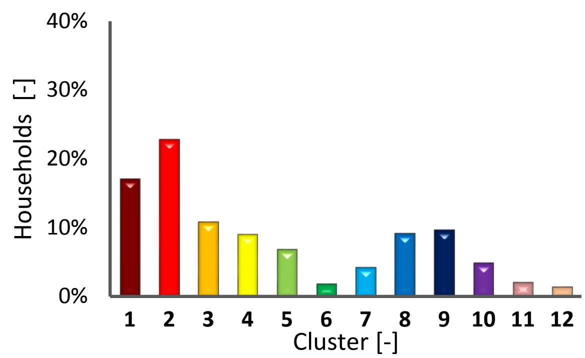
(c) Criterion#3



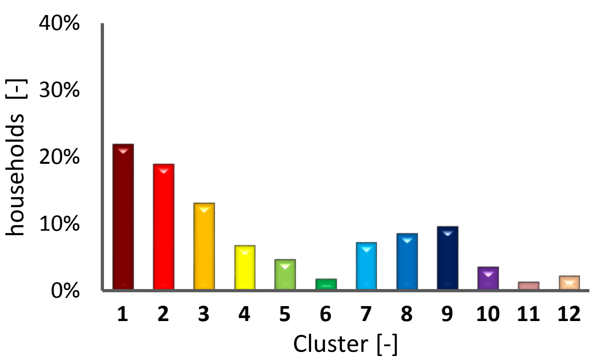
(d) Criterion#4



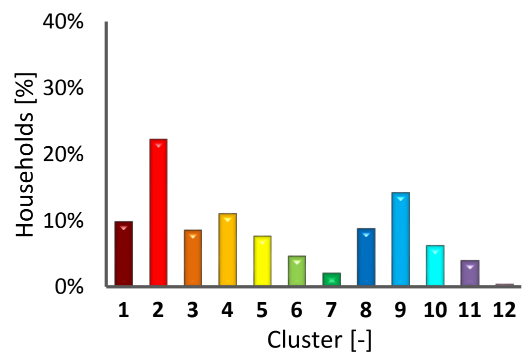
(e) Criterion#5



(f) Criterion#6



(g) Criterion#7



(g) Criterion#8

Figure 5. Applications of the fuel poverty criteria to the household segmentation: distribution of households that meet a certain condition, within each cluster (Refer to Figure 1 for the cluster classification within the national household segmentation)

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Generally speaking, the proposed analysis shows that there are some groups of households where the level of vulnerability with respect to fuel poverty, is quite low (i.e., cluster#4), while others in which the risk is high (cluster#12, cluster#7). The main descriptive results are as follows (Table 2):

- Criterion#1. cluster#1 (39.7%), cluster#2 (21.2%), cluster#3 (16.2%) and cluster#7 (16.2%) contain a high percentage of household satisfying this criterion;
- Criterion#2. cluster#12 (31.9%), cluster#10 (25.2%), cluster#8 (24.2%) and cluster#11 (22.1%) contain a high percentage of household satisfying this criterion;
- Criterion#3. cluster#7 (10.1%), cluster#1 (8.2%) and cluster#3 (8.0%) contain a high percentage of household satisfying this criterion;
- Criterion#4. cluster#12 (50.9%) and cluster#11 (45.1%) contain a high percentage of household satisfying this criterion;
- Criterion#5. cluster#12 (22.6%), cluster#11 (17.0%), cluster#8 (10.7%) and cluster#10 (10.6%) contain a high percentage of household satisfying this criterion;
- Criterion#6. cluster#7 (53.0%), cluster#8 (46.5%), cluster#3 (42.0%) and cluster#1 (40.9%) contain a high percentage of household satisfying this criterion;
- Criterion#7 cluster#7 (18.2%), cluster#12 (11.1%), cluster#1 (10.6%) and cluster#3 (10.2%) contain a high percentage of household satisfying this criterion.
- Criterion#8; cluster#7 (44.7%), cluster#11 (11.1%) and cluster#6 (43.0%) and cluster#3 (41.5%) contain a high percentage of household satisfying this criterion.

Looking closer to the results, we may provide some additional insight by looking at the data provided in Table 2 considering two different perspectives: (a) most vulnerable clusters for a given criteria and (b) the most critical criteria for a given cluster. Concerning the most vulnerable clusters for a given criteria, the main results are as follows. The indicator that evaluates whether energy expenditure is less than half the median suggest an higher risk of fuel poverty in cluster#1; conversely, indicators regarding the incidence of energy expenditure on the total expenditure, energy expenditure above twice the average and energy expenditure higher than food expenditure suggest an higher risk of fuel poverty in cluster#12. Instead, the remaining indicators (i.e., absolute poverty, scarce economic resources, insufficient economic resources, comfort-based indicators), suggest a higher risk of fuel poverty in cluster#7. Concerning the most critical criteria for a given cluster, the main results are as follows. In cluster#1 the greatest vulnerability present is linked to economic factors; in cluster#2, #5 and #9 the greatest vulnerability is observed with respect to the comfort-based criterion; cluster#3 is similar to cluster#1, but the risk of not reaching the heat requirement is slightly higher; in cluster#4 there is a large number of household with insufficient economic resources; cluster#6 proves that it is difficult to achieve adequate thermal comfort, even when compared with rather high energy costs; in cluster#7 the highest levels of risk of fuel poverty is identified, with particular reference to two indicators: (a) decrease in the economic resources and (b) thermal comfort. It is observed that household in cluster#8 use an high percentage of available income to achieve adequate energy comfort, and the risk of not achieving such comfort is on average high; cluster#9 is among the clusters with the lower level of vulnerability; also in cluster#10 a non--- negligible vulnerability is observed with respect to the comfort-based criterion, but no other indicator seems to have high incidence; in cluster#11 there is a high risk of having high energy expenditures , with high incidence on the total expenditures; finally, cluster#12 is associated with a general high-fuel poverty incidence higher overall risk, with characteristics similar to the previous cluster.

Further insights in the results can be provided by looking at the data in Figure 5. The households with annual per-capita energy expenditure lower than half of the median are mostly located within cluster#1 and cluster#2; households with high incidence of the energy expenditure on the total expenditure, are mainly located in cluster#2, and, subsequently, in clusters#1, 3, 5 and 8; with respect to the absolute poverty indicator, most vulnerable households are located in clusters#1, 2 and 3; by evaluating if the energy expenditure exceeds twice the median, it is noted that the higher fraction is inside cluster#9; households spending more for energy than for food are mainly located in clusters#2, 9 and 8; the distributions of households with scarce and insufficient economic resources are very similar, for both of them the highest values are in cluster#1 and 2. The thermal comfort indicator identifies that families who not satisfy 75% of the minimal comfort are mostly situated in clusters#2 and 9. A more complete discussion can be proposed by observing the whole set of indicators. To this ends, Figure 6 presents an alternative way to present vulnerable clusters; in particular, it provides a graphical representation of the percentage of families, within each cluster that satisfy at least 2, 3 or 4 criteria. In this respect, cluster#11, 12 and 10 are more vulnerable; if it is required that at least three of the indicators to be satisfied remain the same groups but with different sorting: cluster#12, 11 and 10; increasing the constraint, with 4 indicators, the most vulnerable groups are cluster#12, 8, and 10-11 at the same level.

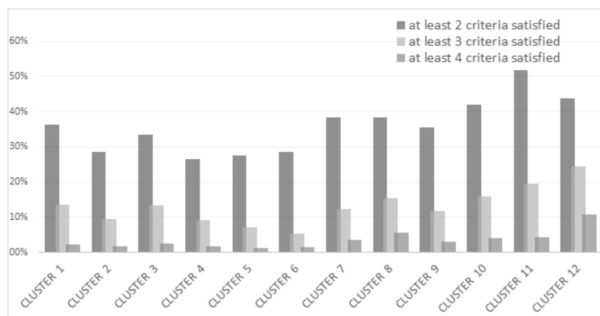

Figure 6. Percentage of households within each clusters that satisfy a certain number of indicators

4. CONCLUSIONS

Using a nationally representative sample of the Italian households, this paper contributes to the existing discussion on fuel poverty. In particular, we applied to a national household segmentation different indicators taken from the literature, and we have further developed a novel indicator based on the minimum thermal comfort-constrain. The proposed analysis shows that there are some groups where the level of vulnerability with respect to fuel poverty, is quite low (i.e., cluster#4, Figure 1), while others in which the risk is high (cluster#12, cluster#7, Figure 1). It is worth noting that this analysis is a preliminary assessment and future studies shouldbe applied by using additional datasets, also including income data. On the practical point of view, this study suggests that there are some stratification of the Italian households

DOI: http://dx.doi.org/10.17501..

more vulnerable with respect to fuel poverty issues. This outcome is of fundamental importance to help policy makers in developing incentives to tackle the fuel poverty issues at the household level.

5. ACKNOWLEDGMENTS

This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE S.p.A. and the Ministry of Economic Development - General Directorate for Nuclear Energy, Renewable Energy and Energy Efficiency stipulated on July 29, 2009 in compliance with the Decree of March 19, 2009. Authors are grateful to ISTAT for providing the micro-data used in this paper.

6. REFERENCES

[1] Boardman, B. 1991. *Fuel poverty: from cold homes to affordable warmth*, Pinter Pub Limited, London, UK.

[2] Li, K., Lloyd, B., Liang, X. J., and Wei, Y. M. 2014. Energy poor or fuel poor: What are the differences?. *Energ policy*, 68, 476-481. DOI= https://doi.org/10.1016/j.enpol.2013.11.012.

[3] Liddell, C. 2012. Fuel poverty comes of age: Commemorating 21 years of research and policy. *Energ policy*, (49), 2-5. DOI= https://doi.org/10.1016/j.enpol.2012.02.036.

[4] Herrero, S. T. 2017. Energy poverty indicators: A critical review of methods. *Indoor Built Environ*, 26(7), 1018-1031. DOI= https://doi.org/10.1177/1420326X17718054.

[5] Karásek, J., and Pojar, J. 2018. Programme to reduce energy poverty in the Czech Republic. *Energ policy*, 115, 131-137. DOI= https://doi.org/10.1016/j.enpol.2017.12.045.

[6] European Observatory on Energy Poverty (EPOV). www.energypoverty.eu.

[7] Faiella, I., Lavecchia, L., and Borgarello, M. 2017. Una Nuova Misura Della Povertà Energetica Delle Famiglie (A New Measure of Households' Energy Poverty). *Questioni di economica e finanza (occasional papers)*, 404.

[8] Romero, J. C., Linares, P., and López, X. 2018. The policy implications of energy poverty indicators. *Energ policy*, 115, 98-108. DOI= https://doi.org/10.1016/j.enpol.2017.12.054.

[9] Heindl, P. 2015. Measuring fuel poverty: General considerations and application to German household data. *FinanzArchiv*, 71(2), 178-215.

[10] Italian National Institute of Statistics (ISTAT). 2017. Household Budget Survey: microdata for research purposes (reference year: 2015).

[11] Besagni, G., and Borgarello, M. 2018. The determinants of residential energy expenditure in Italy. *Energy*, 165, 369-386. DOI= https://doi.org/10.1016/j.energy.2018.09.108.

[12] EUROSTAT, 2010 Household Budget Survey.

[13] Ürge-Vorsatz, D., and Herrero, S. T. 2012. Building synergies between climate change mitigation and energy poverty alleviation. *Energ policy*, 49, 83-90. DOI= https://doi.org/10.1016/j.enpol.2011.11.093.

[14] UNI EN ISO 13790:2008. 2008. Prestazione energetica degli edifici - Calcolo del fabbisogno di energia per il riscaldamento e il raffrescamento.

[15] Capozza, A., Carrara, F., Gobbi, E., Madonna, F., Ravasio, F. and Panzeri, A. 2013. Analisi tecnico-economica di interventi di riqualificazione energetica del parco edilizio residenziale italiano. Rapporto RdS 14002104.

[16] Ballarini, I., Corrado, V., Madonna, F., Paduos, S., and Ravasio, F. 2017. Energy refurbishment of the Italian residential building stock: energy and cost analysis through the application of the building typology. *Energ policy*, 105, 148-160. DOI= https://doi.org/10.1016/j.enpol.2017.02.026.

[17] D.P.R. 16 aprile 2013, n 74. 2013. Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'art. 4, comma 4, della legge 9 gennaio 1991, *Gazzetta Ufficiale della Repubblica Italiana*.

[18] Madonna, F. and Corrado, V. 2014. Studio sulla riqualificazione energetica di edifici residenziali Rapporto RdS 14002701.

[19] Mazzarella, L. 1997. Dati climatici G. de Giorgio. *Proceedings of giornata di studio Giovanni De Giorgio*, (Milan, Italy, November 18, 1997).

[20] Madonna, F. and Quaglia, P. 2016. Riqualificazioni energetiche: benefici di comfort e costi. *Internal report*.

[21] Comité Européen de Normalisation (Brussels). 2007. CEN Standard EN15251 - Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics.

[22] Autorità di Regolazione per Energia Reti e Ambiente (ARERA).www.arera.it.