Subjective Well-Being and Energy Poverty: new insights from the combination of objective and subjective indicators.

ERICA DELUGAS
University of Cagliari
edelugas@unica.it

RINALDO BRAU
University of Cagliari
brau@unica.it

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Abstract

This paper studies the relationship between energy poverty and individual subjective well-being by exploring the potential of using both subjective and objective indicators to measure energy poverty. We use data from the Italian version of the Survey on Income and Living Conditions to build a multidimensional energy poverty index (MEPI). We contribute to the current literature on energy poverty by showing that MEPIs can be used in econometric analysis. In particular, we use a simultaneous bivariate ordered probit model to account for possible endogeneity related to the presence of subjective indicators within the components of the MEPI. The estimations show that being energy poor at the highest severity level reduces of about one third the probability of being high or quite satisfied (at least 7, on a scale from 1 to 10). On the contrary, no effects are detected with the affordability indicator. We claim that modelling energy poverty in a deprivation framework offers new insights into the understanding of the welfare losses perceived by individuals, especially to identify the most vulnerable households to be targeted with adequate supporting policies.

***JEL Classification**: C35, I31, I32*
***Keywords:** multidimensional energy poverty, subjective well-being, limited dependent variable methods, welfare analysis*

1. INTRODUCTION

Even in rich countries, an important share of the population may be unable to buy a fundamental set of goods and services based on energy use. According to Building Performance Institute Europe (Atanasiu, Kontonasiou, and Mariottini [2014]), in 2012 about 10.8% of the European population was unable to keep their home adequately warm or were living in energy poverty(henceforth EP). The size of the problem has been increasing over the last 15 years. People classified as living on an EP condition usually spend a high share of their income in electricity, oil and gas, live in inefficient and unhealthy dwellings, and are exposed to severe consequences concerning health, social exclusion, and overall household welfare. The earliest policies to support vulnerable citizens took place in the United Kingdom, around 1990, while, some other European countries have started to take into account EP as a different phenomenon from income poverty and implemented specific supporting programs in more recent times. Since 2006, the European Union has pushed for spreading energy poor supporting policies all over the European countries[1]. According to the latest projects run by

[1] See European Commission, EPEE 2006.

the European Commission, EP should be officially considered a different phenomenon from income poverty to be separately analysed.[2]

Previous studies (Boardman [1991], Hills [2011], Hills [2012], Welsch and Biermann [2017]) have reported that energy poverty is a complex phenomenon that - though strictly related - has its own peculiarities with respect to income poverty. We believe that this entails that proper identification of energy poor people is a complex task that cannot be exclusively based on monetary indicators derived from variables such as energy prices and expenditures. The scope for going beyond money-metric measures is well documented by the economic debate on welfare analysis, where subjective well-being (henceforth SWB) approaches[3] are often used as a measure of welfare.[4] SWB approaches have been applied to different fields, e.g. health (Ferrer-i-Carbonell and B. M. v. Praag [2002]), social science (Frey [2001]) , evaluation of public goods (Luechinger [2009]) and energy (Welsch and Biermann [2014b], Welsch and Biermann [2014a]).

For the analysis of EP, the SWB perspective has been applied in a recent study by Welsch and Biermann [2017]. This work investigates the effects on life satisfaction of electricity, oil and gas prices (standard "objective" measures) in different European countries, between years 2002-2011. The results show a negative effect of energy prices on life satisfaction, as expected. Likewise, Biermann [2016] considers three types of fuel poverty measures, but all involving households expenditure on energy, finding a significant negative effect on SWB that goes beyond the effect of being income poor. Other studies have taken a SWB perspective when trying to define a subjective measure of EP, as Okushima [2017], Papada and Kaliampakos [2016], Rehdanz et al. [2015], Lawson, Williams, and Wooliscroft [2015] and Waddams Price, Brazier, and Wang [2012], which highlight the need for a definition of a multidimensional objective and subjective indicator to give an overall view of the issue.

What is apparently missing in the extant literature is an analysis of individuals' life satisfaction based on subjective measures of EP. For this reason, our study investigates how SWB is affected by EP by introducing the use of a multidimensional index composed of both subjective and objective indicators of household energy deprivation. We believe that improving analyses based on subjective perception is of particular relevance when dealing with developed countries, in which basic material needs are usually ensured. Compared to the use of current methodologies where only the impact on the individual welfare of energy prices and expenditure-related measures is considered, we document that the modelling of individual satisfaction is sharply improved when using an index of energy poverty that identifies the poor by adopting a deprivation approach.

We use the Italian version of the European Union Survey on Income and Living Conditions (henceforth ITSILC). The national version of SILC allows us to have access to a broader piece of information on dwelling conditions and energy expenditure than the standard European questionnaire, and at the same time, to exploit the recently introduced information on SWB inside the standard questionnaire. Indeed, they include a question about the degree of life satisfaction in a specific module on social exclusion, which is asked to be evaluated with a Likert scale of 10 levels. The data

[2] See EU Fuel Poverty Network and the last project named European Energy Poverty Observatory.

[3] In this study, the words satisfaction, subjective well-being and utility are meant as synonymous

[4] See OECD Better Life Index 2013.

refer to 2013.
The empirical analysis is conducted in two stages. The first one is an explorative description of the energy poverty manifestation in Italy. The indicators chosen to construct the index refer to the dwelling conditions, explaining the source of the energy inefficiency. The second one is dedicated to the econometric analysis of the relationship between the SWB and the EP indicator by applying a bivariate ordered probit estimation on a system of two simultaneous equation. This model also enables us to deal with endogeneity problems due to unobserved factors joint to the reverse causality that occurs with some of these unobservables (i.e. income: are individuals happier because they have more wealth or the happier individuals are more likely to work more and gain more money?). When relying on panel data sets, endogeneity in a SWB framework is often addressed by using fixed effect estimation methods. In our case, in which data only refer to a specific survey wave, simultaneous system estimation allows us to identify the causal relationship between EP and life satisfaction by means of exclusion restrictions referred to the year of building the dwellings.
The empirical analysis confirms theoretical predictions. On the one hand, a significant negative relationship between SWB and EP is detected. On the other hand, we document the strength of subjective indicators in explaining the impact of EP on SWB with respect to traditional measures like the share of income spent on energy consumption or the mere energy prices.
The paper is structured as follows. In sections 2 and 3 we report a review of energy poverty measurement and a literature background on subjective well-being approach. In section 3 we present the conceptual model in which it is framed for the empirical analysis. In section 4 it is explained how this paper explores the multidimensional approach applied to energy poverty and it is presented the description of the index construction and the Italian results; Section 5 illustrates the results of the econometric analysis. Finally, section 6 concludes.

2. Energy Poverty, its measurement and the subjective well-being approach

In this section, we briefly present a literature review of the two main frameworks within which our work aim at contributing, namely the discussion on energy poverty measurement and the links of subjective well-being approach and energy poverty.

2.1. Energy Poverty Measurement

Considering a framework consistent with the economic conditions of developed countries, EP measurement might be separated into two main approaches depending on which dimension leads the researcher in the analysis, viz. the affordability and the energy deprivation approach. Strictly speaking, these approaches may be associated with the broader poverty field and be seen as the uni-dimensional and multi-dimensional way of measure energy poverty. The former focuses on thresholds that fix the maximum accepted level of a unique dimension as income (or expenditure) share spent on energy consumption, whereas the latter focus on collapsing the information of several dimensions into a single composite index.
The main affordability indicators can be classified into three groups. 1) The headcount energy ratio, known as The Ten Percent Rule, which counts as poor individuals spending more than the

10% of their disposable income on energy consumption without any constrains[5]. The so-called 2M indicators, double mean or double median, linked to the Boardman indicator, which count as energy poor the individuals spending more than the double median (or mean) expenditure share. 2) The Low Income High Costs (Hills [2011] and Hills [2012]), which is a composite indicator that sets an income poverty line and counts as energy poor the individuals who spend more than 60% of the median of the national disposable income distribution. 3) The Minimum Income Standard (Moore [2012]), which considers as energy poor those individuals lacking a minimum income standard after paying housing costs and energy costs. Close to Moore's indicator is the Residual Income Indicator (Miniaci, Scarpa, and Valbonesi [2014]), which is aimed at understanding how many (not energy related) goods an individual can purchase apart from the energy consumption. All these indicators allow us to measure how much energy poverty insists on households or individuals, and are helpful in constructing welfare actions to support energy poor in terms of money transfers.

The discussion on the affordability approach remarks on the proper identification of energy poor individuals and the respect of standard income-poverty axioms when the variables by means of which affordability is measured change their values Heindl and Schuessler [2015]. The literature debate on the definition of the concept of energy or fuel poverty drives the *ratio* of the identification strategy. Boardman [1991] gives a starting point on fuel poverty measure, which has been extensively used and debated in the economic literature. Boardman defined that energy poverty was occurring when any household needed to spend more than 10% of its income on total fuel use. Building on a similar approach, more recently Hills [2011] and Hills [2012] has proposed that fuel poverty should only focus on poor people. Finally, Moore [2012] frames fuel poverty within the Minimum Income Standard [6], which is similar to several income poverty measures that focus on the adequate minimum income required to satisfy primarily needs.

As an alternative to the previous series of studies, the energy deprivation approach focuses on how energy deprivation affects people when living in inefficient energy houses. J. Healy [2003] talked about fuel poverty as well but in a completely different sense. He points out that all the measurement problems linked to consumption of energy could be overcome by taking into consideration both subjective and objective indicators of energy efficiency of houses. As an aside, the deprivation approach first allows the researcher to avoid the loss of information due to the unidimensional approach, considering the material manifestations of energy poverty in terms of living in unhealthy dwellings. Finally, it allows researchers to understand the energy poverty intensity experienced by the energy poor, enriching the mere incidence information given by an affordability measure (e.g. to be under high risk of developing breath illnesses or being at risk of social exclusion because of dwelling's conditions). Therefore, in the energy poverty framework, the deprivation approach shows the importance of considering the dimensions of energy poverty similarly to what multidimensional poverty approach (e.g. Sen 1976 and 2012; Chakravarty [2009], Atkinson [2003] Alkire and Foster [2011]) does on the unidimensional-income poverty.

Following Healy's definitions, several indexes and indicators have been developed at the European level. J. Healy [2003], J. D. Healy and Clinch [2004] and Thomson and Snell [2013] use indicators

[5] This approach has also been developed with multiple thresholds, in order to improve its adaptability to differentiated-energy demand Faiella and Lavecchia [2015].

[6] It is an index that set the minimum income required by an individual not to be considered energy poor. Mainly, it targets an individual as poor if her income it is lower than that minimum threshold, after accounting for the energy consumption.

classified as objective and subjective (e.g. presence of damp walls and/or floors, lacking central heating or rotten window frames; to cannot afford to heat home adequately, to be unable to pay utility bills or lack of adequate heating facilities) to do cross-section and within country analysis. These indicators are meant to measure the different dimensions of dwelling inefficiency and to report subjective deprivation and social exclusion, allowing the scholars to measure to some extent the awareness of people of living in energy poverty as well. This approach has been criticised very often, and most researchers raise objections on using these measures, except to enhance the general knowledge about it. However, although it highlights critical dimensions, some problems could arise in identifying the affected individuals. For instance, Healy's indices lack rigorous poor's identification process. Moreover, it does not seem plausible that people are considered poor even though they suffer from only one deprivation over several. The status of deprived might be caused by other factors apart from energy poverty. Hence, strengthening the use of non-monetary indicators could be done by testing the respect of income poverty axiom, both discussed and broadly shared by the literature. Previous works have said very little about inefficiency indices and the respect of poverty axioms.

In principle, affordability and energy deprivation approaches can be combined. Nussbaumer, Bazilian, and Modi [2012] construct a Multidimensional Energy Poverty Index (MEPI), which focus on the deprivation experienced by households in several African countries in terms of energy access and consumption, by applying the methodology introduced in the poverty literature by Alkire and Foster Alkire and Foster [2011], with the aim to enable the researcher to analyse the incidence as well as the intensity of the multidimensional poverty. The MEPI has been applied to a global analysis of energy poverty in developing countries by Nussbaumer, Nerini, et al. [2013]; by Iddrisu and Bhattacharyya [2015] to make a comparison in sustainable energy development, and by Sadath and Acharya [2017] for analysing the energy poverty issue in India. Finally, Okushima [2017] apply the MEPI to evaluate energy poverty in Japan after the Fukushima accident. He defines the income dimension, energy costs and energy efficiency of housing.

Building on this recent stream of literature, in this paper we exploit the multidimensionality given by objective and subjective indicators of energy deprivation and show how the J. Healy [2003] identification strategy can be enhanced by using MEPIs in regression analysis, once properly accounting for the ordinal nature of this family of indexes.

2.2. Subjective Utility and Energy Poverty

The subjective utility is more and more common in economic literature. Satisfaction is measured within our mind on a continuous (latent) scale ranging from completely dissatisfied to completely satisfied. In practice, it is unlikely to precisely express satisfaction on a continuous scale[7] (B. V. Praag and Ferrer-i-carbonell [2006]). Indeed, satisfaction is usually recovered from answers that use rankings, e.g. from excellent to very bad, or numerical scale. Satisfaction self-assess questions are instrumental in understanding individuals behaviours and choices, especially when observed over time. Besides, it can elicit information on individual perceived losses caused by social exclusion,

[7] As shown by extensive literature, some assumptions are required to validate the analysis when applying the SWB approach (Frey [2001], Ferrer-i-Carbonell [2005], B. V. Praag and Ferrer-i-carbonell [2006]). For a review of main empirical analyses see Dolan, Peasgood, and White [2008].

health deprivation, or more generally material deprivation, to better design supporting public policies.
The latent individual utility is expected to be influenced by several factor, for instance income, health, leisure, job characteristics, accommodation, education, social exclusion, marriage,(Frey [2001]; B. V. Praag and Ferrer-i-carbonell [2006] Ferrer-i-Carbonell [2013] ; Andrew E Clark, Frijters, and Shields [2008]; Bellani and D'Ambrosio [2011]; Welsch and Biermann, 2017; Andrew E Clark, Frijters, and Shields [2008]). In Andrew E Clark, Frijters, and Shields [2008] and in Bellani and D'Ambrosio [2011] the use of deprivation indicators is shown to be more relevant than the use of traditional monetary indicators to capture the effect of poverty on SWB. With respect to energy, the SWB approach was used by Welsch and Biermann [2014a] in an assessment of electricity supply structures in Europe, Welsch and Biermann [2014b] and Rehdanz et al. [2015] in studies of the Fukushima nuclear accident, Welsch and Biermann [2016] in a study of nuclear power plant externalities in Switzerland, and Moellendorff and Welsch [2017] in an analysis of renewable power externalities in Germany.
Welsch and Biermann [2014a] and Welsch and Biermann [2014b] firstly use experienced utility (SWB) to represent preferences relationships over electricity supply system across countries. They find that SWB varies with the difference of attributes of the electricity system. Secondly, they use again the experienced utility proxied by SWB to interpret the people's change in preference on nuclear power after the nuclear accident; they found that the relationship between SWB and nuclear power become statistically significant after the accident. Rehdanz et al. [2015] assess the same change in SWB using a quasi-experimental difference-in-difference approach, obtaining different results depending on each sub-sample they analyse. A few recent studies (Waddams Price, Brazier, and Wang [2012]; Lawson, Williams, and Wooliscroft [2015]; Papada and Kaliampakos [2016]) have jointly considered objective and subjective measures of energy poverty. Waddams Price, Brazier, and Wang [2012] highlight the difference in reporting self-assess energy poverty and being considered energy poor because of the expenditure share in energy consumption. They found that 28% of individuals of their sample is energy poor under 10% rule; 16% feel unable to keep their homes warm. Nevertheless, less than the half of 16% is not contained into 28%. Lawson, Williams, and Wooliscroft [2015] find that the energy poor of the different measure do not overlap. They raise the question of understanding the trade-off that those people face to better support these citizens. Papada and Kaliampakos [2016] analyse the characteristics of energy poor under the 10% rule, objective and subjective indicators. They report that 3 out of 4 households self-assess a decrease in other essential goods to cover the energy expenditure.
Hence, starting from those results, it seems reasonable to evaluate the effect of energy poverty in terms of deprivation and terms of subjective well-being.

3. Identifying and measuring energy poverty

The Data. EUSILC is the European survey that reports the statistics on income living condition released by Eurostat. It was launched in 2003, and it has been implemented since 2010 in all EU-27 countries. It is mainly designed to study social exclusion and monitoring poverty in EU. Nevertheless, we have decided to use only the data of the Italian version (ITSILC released by Istat[8])because the EUSILC questionnaire is part of a more extensive national survey that contains a richer set of questions about energy consumption, expenditure and dwelling's inefficiency that the European survey does not include. Both of them are either cross-sectional and longitudinal surveys, but as mention before, our analysis is limited on the cross-sectional part because our primary variable of interest (Individual Satisfaction) has only been collected in 2013 in a special module on well-being. All ITSILC releases are available only at the regional level (NUTS3).

3.1. Energy Poverty Index.

In this section, we first explain the methodology of the multidimensional poverty index applied to the energy poverty issue and show some evidence about the incidence and intensity of energy poverty in Italy.

Combining subjective and objective indicators. In recent years, the focus on the information given by subjective indicators (individual perceptions) has been quite enlarged to many fields. As mention before, we want to exploit the multidimensionality given by subjective and objective energy deprivations. All over this paper, energy poverty will be defined and measured as energy efficiency problems[9], and it is explored the application of a multidimensional poverty approach to energy poverty dimensions. Indeed, as already shown by several works, when analysing energy poverty and households energy-related choices and behaviours, the perception of the deprivations plays a significant role. Hence, to combine this information with more objective non-monetary indicators, the methodology presented strictly follows Alkire and Foster [2011] multidimensional poverty approach, adapting it to subjective and objective deprivation.
This particular methodology allows analysing both of the incidence and the intensity of energy poverty across individuals (households). In Table 1 we present the energy deprivations (henceforth ed) that might be suffered by the individuals, which represent the several dimensions of housing inefficiency, and their main statistics. These deprivations are objective and subjective indicators of the inefficient dwelling's condition; ed1, ed2, ed3, ed5 are the objective ones, directly collected by the interviewers; ed4 is an information recovered from the analysis of the expenditure habits of the individuals and takes 1 when they declare no energy expenditure for all the alternative.

Table 1: *Energy deprivation questions and statistics*

Variable	Question	Mean	Std. Dev.	Min.	Max.
ed1	Has the household been in arrears due to financial difficulties for utility bills for the main dwelling?	0.09	0.29	0	1
ed2	Has the dwelling any problems with the damp on walls, floors, ceilings or foundations?	0.18	0.39	0	1
ed3	Has the dwelling any problem with damage roof, ceilings, doors, windows or floors?	0.11	0.32	0	1
ed4	Computed on the basis of the lack of any heating expenditure.	0.05	0.21	0	1

[8]Italian national statistical institute
[9]The official definition of Ireland is considered as a landmark.

ed5	Is your dwelling too dark, meaning is there not enough day-light coming through the windows?	0.06	0.24	0	1
ed6	Can your household afford to keep its home adequately warm?	0.16	0.36	0	1

Source : ITSILC 2013. The first five items are classified as objective ones, reporting the presence or not of the lack, whereas the last is classified as a subjective indicator. The variables can be find into the dataset as hs021, umid, tetti, hs160, hh050, while ed4 is recovered from the energy-specific expenditure analysis. All of them are dichotomous variable so that they assume value 1 when the deprivation exists, 0 otherwise.

According to the data, the most affecting deprivation is the presence of damp with 18%; having any problems with roofs and window fixtures concerns 11% of the sample. The less affecting are living in a too dark dwelling and not to have heating facilities. The subjective indicator impacts 16% of the sample. The key feature of the methodology is the presence of two thresholds that allow shaping an identification function for the energy poor. This process stays at an intermediate point between the union and the intersection identifications rules used in the poverty measurement literature (e.g., Atkinson [2003]; Chakravarty [2009]). The former classifies as poor each person who presents at least one deprivation. On the contrary, the intersection identifies as poor only the individual who counts all the deprivations. Alkire and Foster [2011] develop an identification strategy that stands in-between of the two, given the setting of an arbitrary threshold.
Let n be the sample size, $d = 6$ the items presented in Table 1. Then define $g = [g_{ij}]$ as the nxd matrix of energy poverty dimension, where g_i represents the row vector of a single individual. The index is made up of two cut-offs, the deprivation one and the energy poverty one. The former concerns the threshold of being deprived by a specific dimension and the latter fixes how many deprivations the person should have in order to be identified as poor. Hence, define z as the deprivation row cut-off vector of ones[10] so that $z = [z_1, \ldots, z_d] = [1, \ldots, 1]$. Applying the z cut-off to g, $g^p = [g^p_{ij}]$ is obtained, where it represents the 0-1 deprivation matrix so that $g^p_{ij} = 1 \quad if \quad g_{ij} = z_j \quad and \quad g_i j^p = 0 \quad if \quad g_{ij} \neq z_j$. At this stage, it is necessary the count of deprivation suffered by each and the identification itself, so that $c = |g^p_i|$ is the number of deprivation suffered by a single individual. Therefore, the identification function[11] $\vartheta = \vartheta(g, z)$ takes value 1 when a person is identified as poor and 0 otherwise. As already said, the union identification implies:

$$\vartheta(g_i, z) = \begin{cases} 1 & iff \quad c_i > 1 \\ 0 & otherwise \end{cases} \tag{1}$$

whereas the intersection identification implies:

$$\vartheta(g_i, z) = \begin{cases} 1 & iff \quad c_i = d \\ 0 & otherwise \end{cases} \tag{2}$$

[10]All the items are dummies so that experiencing the deprivation is equal to 1 by definition.
[11]See Chakravarty [2009] .

Therefore, as in our computation, it might be apply:

$$\vartheta(g_i, z) = \begin{cases} 1 & iff \quad c_i > k \quad where \quad 0 < k < d \\ 0 & otherwise \end{cases} \tag{3}$$

Given the identification function, we can compute the Energy Headcount Ratio (EH) and the Adjusted Energy Headcount Ratio (AEH):

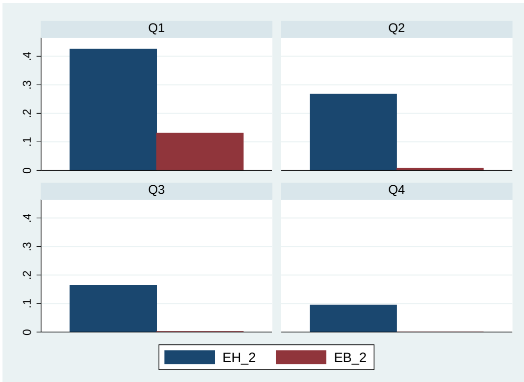
$$EH = EH(g, z) \quad where \quad s = 1, 2 \quad EH = \frac{p}{n} \quad and \quad p = \sum_{i=1}^{n} \vartheta(g_i, z) \tag{4}$$

$$AEH = A \times EH(g, z) \tag{5}$$

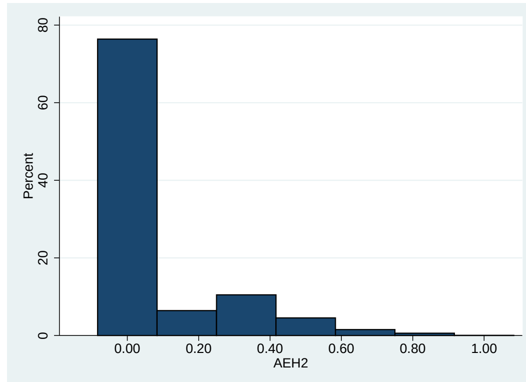
where A is the average deprivation across the energy poor, $A = \frac{\sum_{i=1}^{N} g_{ij}}{d}$ and N indicates the total number of energy poor. As shown in Alkire and Foster [2011], the most important property of the AEH is given by the dimensional monotonicity. The EH only counts the incidence of the poor, but it does not change when a poor individual becomes deprived of a new determinant (or improves her situation). Weighting the EH with the average deprivations across the energy poor let the metric AEH change whenever the individuals' deprivation count changes.
Both (4) and (5) might be computed using different weighting schemes and values for k. The value of the poverty cut-off is arbitrarily chosen according to the value taken by c_i after applying the weights to each deprivation.
In classical multidimensional poverty indices, the problem of the choice of the weights always arise. The choice of weights it is a crucial feature in making multidimensional indices because they determine the trade-offs between the different dimensions Decancq and Lugo [2012a]. All the deprivations describe the same latent variable so one might assume reasonable to impose equal weights. However, we construct several scenarios; a first one that assigns more weight to the subjective indicator, such that $w_o = 0.1$ is the objective weight and $\sum_{o=1}^{d-1}(w_o) = 0.5$ and $w_s = 0.5$ is the subjective weight, with $\sum_{j=1}^{d}(w_j) = 1$. A second scenario is defined just defining $w_j = [0, 1]$ and $\sum_{j=1}^{d}(w_j) = 1$. In the next part, we first present our results using the different-weight scenario, and then, we conduct a sensitivity analysis regarding the single contribution of each indicator to the metric.

3.2. Energy Poverty in Italy.

The main goal of our descriptive analysis is showing how erratic the results of energy poverty incidence can be when using whether a single affordability measure or a composite index that aggregates information on inefficient housing. To reach our purpose, Figure 1(a) reports the results obtained by computing the different weights scenario(EH2) and an affordability measure, namely EB2. $EB2 = \frac{\sum_{i}^{N} v_i}{N} \times 100$, where $v_i = 1 \quad iff \quad electricity \quad consumption > 0.10 \times income \quad and/or \quad fuel \quad consumption > 0.05 \times income$. The average energy headcount ratio displays 23% of the sample as affected by energy poverty, while the 10% Modified Rule targets 3.43%. Figure 1(a) also displays the incidence of energy poverty decomposed by equivalent household. The graphic analysis suggests a decreasing relationship; the richer the household is, the less is affected



(a)



(b)

Figure 1: *Histogram (a) reports the distribution of the energy poverty headcount and the modified 10% rule by income quartiles. Histogram (b) reports the distribution of the adjusted energy poverty headcount.*

by energy poverty in both types of measurement. However, it appears that the affordability measure certainly captures the income problem, but it excludes a large share of individuals targeted by the deprivation metric. Table 2 shows the overlapping percentage of the two metrics. They are surely capturing different vulnerable citizens. The affordability measure is likely to capture only people that are suffering from income poverty, whereas the multidimensional measure is considering all the individuals who are living in inefficient dwellings, including those cannot even afford to reach the threshold to be considered by the affordability measure. Figure 1(b) shows, instead, the intensity of energy poverty measured by AEH2, which is the adjusted headcount ratio computed using different weights, by equivalised income quartiles. The intensity of the energy poverty index decreases as income increases.

Table 2: *Percentage of Energy Poor according to different indexes*

Variable	Mean	Std. Dev.
EB2	0.03	0.18
EH2	0.24	0.42
OVERLAP	0.01	0.12
Only EH2	0.22	0.42
Only EB2	0.02	0.14

My own elaboration on ITSILC 2013

Sensitivity Analysis We extend our analysis by observing: 1) how the share of energy-poor changes when changing the threshold for the identification function; 2) how the share changes considering a different number of total dimensions and 3) the changes induced by introducing the 10% Modified Rule as a proxy of energy-induced income deprivation.

Table 3 displays the results of the sensitivity analysis. Computing these indices, we apply equal weights for each indicator, such that $\sum_{j=1}^{d}(w_j) = 1$. The metrics are calculated using five different thresholds. The extreme thresholds' values correspond the union and intersection identification, so that the former set $k = w \times 1$ and the latter $k = w \times d$. The intermediate values of 80, 90 and 95 are the rescaled number of the deprivations $k = w \times c$ that correspond at the three specific percentiles. Regarding the deprivation choice, we want to show the sensitivity of the metric for each indicator and, in addition, we also extend the set of deprivation at 7, $d = 7$, using EB2 as the seventh deprivation. The table focuses on the incidence of energy poverty, reporting the energy headcount ratio computations. Panel A displays the complete indices; indices in Panel B consider as a benchmark the six-deprivation metric; Panel C considers as a benchmark the seven-deprivation metric. In panel B and C the numbers in the name of the metrics indicate the variable that is missing, referring to the labels presented in Table 1.

As expected, the indices including the affordability deprivation increase the percentage of the energy poor for all the thresholds and combinations of deprivation. *De facto*, the headcount is not sensible to dimension monotonicity and does not change when the deprivations experienced by a poor individual increase. Union and $k = 80$ display the same percentage for any combination of indicators. Intersection threshold does not cross the 1% of the sample, meaning that the intensity of the majority of the energy poor is not the highest.

Table 3: *Energy Poverty Headcount ratio (Percentage)*

	Union	**80**	**90**	**95**	**Intersection**
			Panel A		
EH_all7	40,45%	40,45%	18,49%	7,45%	0,00%
EH_all6	38,89%	38,89%	17,44%	6,88%	0,05%
			Panel B		
EH_1wee	36,20%	36,20%	14,49%	4,76%	0,14%
EH_2wee	32,43%	32,43%	11,59%	11,59%	0,06%
EH_3wee	36,50%	36,50%	13,32%	13,32%	0,06%
EH_4wee	37,03%	37,03%	15,85%	6,18%	0,48%
EH_5wee	37,37%	37,37%	15,58%	5,35%	0,13%
EH_6wee	32,36%	32,36%	12,71%	12,71%	0,07%
			Panel C		
EH_1we	37,99%	37,99%	15,53%	5,35%	0,00%
EH_2we	34,25%	34,25%	12,63%	12,63%	0,00%
EH_3we	38,12%	38,12%	14,47%	14,47%	0,00%
EH_4we	38,60%	38,60%	16,90%	6,73%	0,02%
EH_5we	38,98%	38,98%	16,68%	5,90%	0,00%
EH_6we	34,35%	34,35%	13,66%	13,66%	0,00%

Union identification sets k=1; Intersection identification sets k=d; 80,90 and 95 set as k the number of deprivation at the correspondent percentiles. EH_all7 considers all the indicators; EH_all6 does not consider the affordability indicator; EH_1wee-EH_6wee are computed excluding every time one indicator, considering the base of 6. EH_1we-EH_6we are computed excluding every time one indicator, considering the base of 7.

In this section, we present the theoretical framework within which we are working in and the estimation methodology that we apply in our empirical analysis.

The use of self-assess satisfaction in the economic investigation has led to new findings on the importance of considering the individual satisfaction in welfare analysis. It allows researchers to explore the individual utility losses caused by several life shocks. Also, understanding welfare losses suffered by individuals is essential in order to help government interventions in addressing social welfare problems.

Individual satisfaction allows us referring to welfare as a broader concept than mere income. In this framework, the person who loses in well-being is becoming poorer, and the causes can be several apart from income. The standard economic view on utility and income, in which income is considered the main predictor of utility, describes a monotonic relation between the two. Besides, the magnitude of the changes in utility differs depending on the initial conditions. The higher the income, the more it can be consumed, the more people are satisfied and happy with their life because their utility is increasing and the less the starting income, the more the utility will increase with an income increase. Nevertheless, when using satisfaction and happiness variables to proxy utility, it has been shown that the income is not the main predictor of experienced utility. **Christoph2010** highlights that deprivation indexes perform better in predicting satisfaction levels than income. Moreover, the relative position w.r.t. a reference group has more impact than the single disposable income; also unemployment, personal life shocks and so forth have been identified as significant predictors of satisfaction and happiness (Blanchflower and Oswald [2004], Frey [2001]). Eventually, an important part of the predictor effects might be affected by unobserved heterogeneity as well (Ferrer-i-Carbonell [2005], Blanchflower and Oswald [2004], Frey [2001]). Also, the relationship between income and well-being not always follows a standard pattern monotonically increasing overtime Blanchflower and Oswald [2004], Frey [2001]. Indeed, after a given level of income, it falls or stays stable, but it cannot be stated that a richer country is always a happier country (Frey [2001]). Di Tella, MacCulloch, and Oswald [2001] have discussed the macro determinants of the happiness as GDP levels, unemployment, inflation, quality of the institution, that when following negative trends cause a quite significant decrease in happiness. They also find a monotonic positive relation w.r.t. income and that the structure is similar across countries. In general, the different domains of satisfaction (B. V. Praag and Ferrer-i-carbonell [2006]) as well as the determinants of it (Ferrer-i-Carbonell and B. M. v. Praag [2002]; **Christoph2010**;Ferrer-i-Carbonell [2013]; Ferrer-i-Carbonell and Ramos [2014]) have been widely explored.

Hence, according to the empirical evidence, this paper points to underline how the use of a multidimensional energy poverty measure would be extremely useful in building social intervention. As shown in the previous section, this study proposes a multidimensional energy poverty index, which applies a double cut-off methodology to the energy-poor identification. The first cut-off identifies the deprivation status in each specific dimension; the second one defines as poor only individuals over a given threshold of aggregate deprivations. It leads to a discrete index of several levels between 0 and 1, the higher the value, the more severe is the energy poverty condition.

When adopting a subjective well-being approach, energy poverty can be included as a determinant of individual welfare. Following Decancq, Fleurbaey, and Schokkaert [2015] SWB definition:

$$SF^* = (l_{ik}, R_{ik}, S_i) = S_i(l_{ik}). \tag{6}$$

where SF_i^* is the latent individual satisfaction depending on l_{ik}, meant as the m different aspects of life, which contains among others the energy poverty. Then, define a preference order R_{ik} so that $S_i(l_i)$ represents the individual satisfaction measured by an ordered scale. Therefore, considering l_{ei} be the energy poverty dimension, and $\sum_{i=1}^{K-1} l_{ik}$ all the other aspects of life that can affect SWB, the relationship between individual satisfaction and energy poverty can be expressed by the following system:

$$\begin{aligned} SWB_i^* &= S(\mathbf{X}, EP_i^*, \mu_{iSWB}) \\ EP_i^* &= P(\mathbf{X}, \mu_{iP}) \end{aligned} \tag{7}$$

where X is a vector of the determinants of individual satisfaction and energy poverty, EP^* is the energy poverty dimension and μ_{iSWB} and μ_{iP} represent the unobservable individual heterogeneity which affects the perception of satisfaction and energy poverty(e.g. the general knowledge about the issue itself, the subjective climate perception).

Several covariates we are controlling for are determinants well discussed in previous studies of the satisfaction literature. They include social-economic conditions, demographic determinants, job condition. It is likely that the unobserved heterogeneity affects both SWB^* and EP^* entailing typical endogeneity problems. In order to identify the causal relationship, under the endogeneity problems, we develop our analysis as a triangular system of two equations. The endogeneity problem arises with the inclusion of energy poverty as an explanatory variable of the subjective satisfaction due to the potential correlation between the variable and the two error terms due to unobserved heterogeneity. Hence, the specification of (7) includes at least one exclusion restriction on the vector of explanatory variables such that the effect of the EP^* on SWB^* can be identified.

The endogeneity of Energy Poverty The source of endogeneity of EP^* is mainly due to the presence of measurement errors in reporting subjective information and the presence of unobserved factors, which influence both SWB^* and EP^*, and, consequently, make it correlated with the errors. For instance, it has been discussed by previous works[12] that optimism affects the individual satisfaction and it is likely that subjective climate perception affects the energy poverty condition as well. It is widely recognised in the econometric literature that such an issue can be solved by using fixed effect estimation on panel data. However, we are aware that the endogeneity of EP can be only partially solved because the unavailability of the panel data does not allow us to tackle the endogeneity due to unobserved heterogeneity reasonably constant across time (e.g. personal traits) in such a way. Also, as extensively discussed by Ferrer-i-Carbonell [2013], the reverse causality in SWB is also due to some individual unobservable factors which are not time-invariant, and we are not able to control for them.

Given the nature of the two variables of main interest, we model a system that is jointly estimated by a bivariate ordered probit, which allows us to address the presence of endogeneity in (7) caused by EP^*. Therefore, we based our exclusion restriction on the objective and technical factors that

[12] See OECD Guidelines on Measuring Subjective Well-Being (2013) for a review on measurement error in subjective variables.

influence the probability to be energy poor. Following Bérangère and Ricci [2014] we explore the determinants that are not likely to be correlated to SWB^*. As stressed by Fabbri [2015], the inefficiency of a dwelling is influenced by several determinants. One of those determinants is the year of construction of the building. Indeed, Fabbri [2015] claims that the more recent is a dwelling, the less is likely to have energy inefficiency problems. As a note of caution, we must recognise that the age is a quite imperfect indicator of the inefficiency because the buildings' history often includes property renovations.
Several studies as Fabbri [2015] or Fracastoro and Serraino [2011] have shown that the year of construction contributes at inefficiency even though it is not the year *per se*, but it is a bad history of the building which contributes more. For that reason, we claim that it is likely that the dwelling choice is affected by self-selection. For instance, due to health status, income level or in general personality traits, people might have preferences that lead only to older buildings(e.g. living in historical city centres) or newer (e.g. more salubrious). Following this argument, the individual satisfaction might eventually be still affected whether the year of construction *per se* influences it. Specifically, we control for the individual health status, for the income relative position w.r.t. the reference group, for the dwelling's type and in the robustness check, we also control for the quality of the dwelling and the job sector. Therefore, we control for several of the satisfaction determinants that have already been found by the literature to be significant in explaining the individual utility and might be correlated to energy poverty. Therefore, our assumption claims that conditional on all controls, the energy poverty equation captures any indirect effect of the year on the life satisfaction. Hence, we identify the dwelling's ancientness as our instrument, relevant and uncorrelated to our main dependent variable, which lets us address the endogeneity and estimate the causal relation between SWB and EP.

4.1. A bivariate ordered probit approach

Define the system of the latent variable equations as:

$$\begin{aligned} SWB_i^* &= \beta EP_i + X_i^{'}\theta + e_i \\ EP_i^* &= X_i^{'}\delta + u_i \end{aligned} \tag{8}$$

where SWB_i^* is the latent utility, EP_i is the vector of the energy poverty individual index, X_i is the vector of characteristics that determine the satisfaction and e_i the unobserved heterogeneity vector of the structural equation of SWB_i^*. EP_i^* is the latent energy poverty and X_i contains its determinants. In both equation X denote a set of exogenous variables such that $E(u_iX) = 0$ and $E(e_iX) = 0$ but it is likely that $E(e_iEP^*) \neq 0$.
The latent nature variables does not allow us to observe the real values, but instead, we observe two ordered variables defined as follow:

$$SWB_i = \begin{cases} SWB = 0 \quad if \quad SWB^* \leq c_1 \\ SWB = 1 \quad if \quad c_j > SWB^* \geq c_{j-1} \\ \vdots \\ SWB = J \quad if \quad SWB^* > c_J \end{cases} \qquad EPi = \begin{cases} EP = 0 \quad if \quad EP^* \leq \alpha_1 \\ EP = 1 \quad if \quad \alpha_k > EP^* \geq \alpha_{k-1} \\ \vdots \\ EP = K \quad if \quad EP^* > \alpha_K \end{cases} \tag{9}$$

We also impose the standard assumption on the cut-off points which are monotonically increasing so that $c_0 = \alpha_0 = -\infty$ and $c_J = \alpha_K = +\infty$. Following Calhoun [1989a], Greene and Hensher [2008], Sajaia [2008], the conditional joint probability distribution is expressed by:

$$\begin{aligned} Pr(SWB = j, EP = k \mid EP, X) &= Pr(c_{j-1} \leq SWB^* < c_j, \alpha_{k-1} \leq EP^* < \alpha_k) \\ &= Pr(e_1 \leq c_{j-1} - \beta X_{2i}^{'}\delta + u_i - X_{1i}^{'}\theta \mid EP, X; e_2 \leq \alpha_{k-1} - X_{2i}^{'}\delta + u_i \mid X) \\ &- Pr(e_1 \leq c_j - \beta X_{2i}^{'}\delta + u_i - X_{1i}^{'}\theta \mid EP, X; e_2 \leq \alpha_k - X_{2i}^{'}\delta + u_i \mid X) \\ &= \Phi_2((c_j - \beta X_{2i}^{'}\delta - X_{1i}^{'}\theta)\xi, \alpha_k - X_{2i}^{'}\delta +, \tilde{\rho}) \\ &- \Phi_2((c_{j-1} - \beta X_{2i}^{'}\delta - X_{1i}^{'}\theta)\xi, \alpha_k - X_{2i}^{'}\delta +, \tilde{\rho}) \\ &- \Phi_2((c_j - \beta X_{2i}^{'}\delta - X_{1i}^{'}\theta)\xi, \alpha_{k-1} - X_{2i}^{'}\delta +, \tilde{\rho}) \\ &+ \Phi_2((c_{j-1} - \beta X_{2i}^{'}\delta - X_{1i}^{'}\theta)\xi, \alpha_{k-1} - X_{2i}^{'}\delta +, \tilde{\rho}) \end{aligned} \tag{10}$$

where Φ_2 is the bivariate standard normal distribution, $\xi = \frac{1}{\sqrt{(1+2\beta\rho+\beta^2)}}$ and $\tilde{\rho} = \xi(\beta + \rho)$. The error terms $(e_i, u_i) \sim N(0, \Sigma)$ where $\Sigma = \tilde{\rho}_{jk}$ is the variance-covariance matrix. Sajaia [2008] develops this particular specification and its Stata routine based and refers to it as as simultaneous bivariate ordered probit[13]. It is an extension of the standard bivariate probit specification. It has been used also in health economics (Bünnings and Tauchmann [2015]); education economics (Kalb and Van Ours [2014]); economic psycology (Farrell, Fry, and Risse [2016]).
It follows that the individual contribution to the log-likelihood is then:

$$ln\mathcal{L}_i = \sum_{j=1}^{J}\sum_{k=1}^{K} \mathcal{I}(SWB_i = j, EP_i = k|EP, X) = lnPr(SWB_i = j, EP_i = k) \tag{11}$$

And the log-likelihood function of the entire sample is obtained by summing across observations:

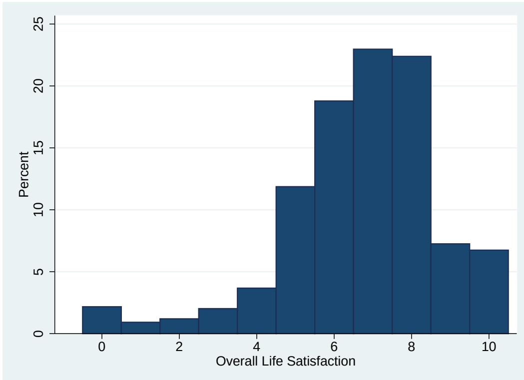
$$ln\mathcal{L} = \sum_{i=1}^{N}\sum_{j=1}^{J}\sum_{k=1}^{K} = \mathcal{I}(SWB_i = j, EP_i = k|EP, X) = lnPr(SWB_i = j, EP_i = k) \tag{12}$$

The identification of the triangular system and the consequent estimation of the parameters of the model is founded on the existence of an exclusion restriction. According to Maddala [1983], the identification is possible whether the two error terms are not independent if and only if the explanatory variable matrix of the first equation does not include all the explanatory variables of the second. Hence, the exclusion restriction allows the **X** matrix in SWB_i^* equation to be a portion of the **X** matrix in EP_i^*. We need to assume that at least one variable in EP_i^* has only an indirect effect on SWB_i^*.

5. Econometric analysis

In this section, we present the variables, the sample and our econometric results.

[13] It is not adequate the use of a two stage control function procedure because of the non linearity of the model.



(a)

(b)

Figure 2: *Graph (a) shows the distribution of the overall satisfaction across the whole sample. Graph (b) reports the distribution of the overall individual satisfaction by the level of energy poverty.*

5.1. Variables and Sample definition.

Following the literature on SWB, we control our main relationship of interest for a set of covariates at the micro level as sex, age, age square, marital status, general health conditions, education level, working conditions, urbanisation level and region. The original sample contained 44622 observation. We drop every incomplete survey record on energy poverty indicators and the subjective well-being question. We also drop all the individuals younger than 16. Table 3 presents the list of variables used for the econometric analysis. In the appendix, Table A(1) reports the simple descriptive statistics for all of them. The sample of the main regression is 23193 that varies in the robustness checks because of missing values of the controls. We compute the dummy variable of all the discrete personal characteristics we want to control for. The equivalised household income (Eurostat equivalence scale[14]) has been used to compute the relative position with respect to the reference group, which has been defined with age, gender and education level.

Table 4: *List of Variables*

Variable Name	Variable Label
Male	1 if male
Age	Age at the date of the interview
Self-assess health 1	very good health
Self-assess health 2	good
Self-assess health 3	fair
Self-assess health 4	poor
Self-assess health 5	very bad health
Married	1 if married

[14]It assigns the value of 1 to the first adult, 0.5 to the second and all the other components at an age equal or over than 14 and 0.3 to each child under than 14.

Divorced	1 if divorced
Never-married	1 if never married
Widowed	1 if widowed
Children	1 if they have children
Pre-Primary	1 if ISCED level = 0
Primary	1 if ISCED level = 1
Low-secondary	1 if ISCED level = 2
Upper-secondary	1 if ISCED level = 3
Post-secondary	1 if ISCED level = 4
Firs-tertiary	1 if ISCED level = 5
Employed	1 if employed
Unemployed	1 if unemployed
Self-employed	1 if self-employed - full and part time
Retired	1 if retired
Isco08	Isco classification 2-digits
Equivalised Income	Equivalised household income
Richer than reference group	1 if richer
Material Deprivation	individual contribution to
	the material deprivation adjusted headcount ratio
Flat	type of dwelling
N. Rooms	Number of rooms available to the household
Owner	1 if dwelling owner
No Urban	living in a no urban area
Quality of dwelling	dwellings quality expressed in rent or subjective rent
Dwelling's construction ancientness	9 levels
Dwelling's construction before 1970	1 if constructed before 1970

The Overall Satisfaction. The subjective well-being variable is an individual question that ranks the degree of satisfaction [15] between a range of eleven levels, from 0 (not at all satisfied) to 10 (completely satisfied). Figure 2 (a) displays the distribution of the SWB across individuals of the sample. As expected, it follows the typical European trend and is left-skewed. Figure 2 (b) reports the distribution of SWB across the levels of our EP index. The individuals that exhibit the highest value of our index display a completely right-skewed distribution. In general, the higher the index, the less satisfied are the individuals. The figure A1 (a) presents the distribution of satisfaction by income quartiles.

Energy Poverty Intensity and Instrument As extensively explained in Section 3, the aggregate intensity of energy poverty experienced by the individuals is measured by our adjusted headcount ratio, AEH2. It is an ordered variable that takes 7 values between 0 and 1. It changes depending on the number of the deprivations suffered by each, and its mean indicates the average intensity

[15] The variable in ITSILC is *PW010*

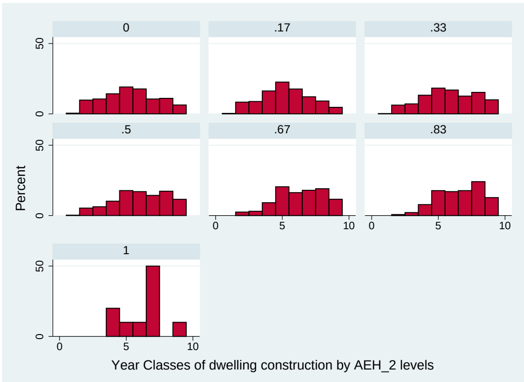


Figure 3: *Graph displays the distribution of the dwelling's construction ancientness by intensity of energy poverty.*

experienced in our sample. Hence, although AEH2 is not a cardinal variable, the individual value of the index can be seen as the degree of energy poverty suffered by each person targeted as poor. Therefore, we exploit this individual contribution to the aggregate metric as an individual proxy of the degree of energy poverty experienced to assess its effect on subjective utility(SWB). Given the endogeneity problem due to measurement errors and unobserved heterogeneity, our identification strategy is based on 1)a set of dummies that indicate the dwelling's construction ancientness 2) a single dummy that takes 1 when the construction has been taken before 1970. The single dummy is used as a robustness check. The original variable contains 9 classes. The classes are defined from 1 to 9, where 1 contains the more recent dwelling (after 2010 up to 2013) and 9 the oldest (before 1900). The classes 2-7 account for 10 years each, class 8 accounts for 1900-1949, while class 9 accounts for any year before 1900. Figure 3 (a) shows the distribution across the sample. The majority of the dwellings are built between the 50's and the 70's. Figure A1 (b) reports the distribution by income quartiles. These distributions are slightly left-skewed, meaning that we observe wealthier people owning more modern buildings than poorer, but the graphics analysis does not suggest a strong dependence between income and year of construction. Figure 3 (b) shows, instead, the distribution across our EP index levels, which is entirely left-skewed for those who experience the more intense EP.

5.2. Results

Table 5 reports the main results of the estimation. Model (1) refers to the equations of our Adjusted EP index and (2) SWB estimated jointly. Our exclusion restriction based on the dummy set of dwelling's construction ancientness (the reference class is 2013-2010) has statistical support for the oldest buildings. All the coefficient are positive as expected. The older the dwelling is, the higher the probability of staying in a more severe energy poverty level. The magnitude of the coefficients is not informative about the size of the effect. Looking at SWB estimation, the AEH2 coefficient is negative and statistically significant. The findings on the other covariates also are consistent with the literature on SWB. The relative position in the disposable income distribution is positive and strongly significant. The multidimensional poverty index is also significant and with the expected sign. Table 2 in the appendix presents the same estimation with a different specification. Instead of the dummy set of instruments, we use a dummy the buildings constructed before 1970. The dummy has strong statistical support. The coefficient of our MEPI is basically equal to the specification in table 5.

Table 5: *Full information maximum likelihood*

	(1)	
	AEH2	SWB
Dwelling's ancientness:		
2000-2009	0.231	
	(0.90)	
1990-1999	0.199	
	(0.78)	
1980-1989	0.284	
	(1.11)	
1970-1979	0.399	
	(1.56)	
1960-1969	0.432	
	(1.70)	
1950-1959	0.606*	
	(2.36)	
1900-1949	0.682**	
	(2.66)	
Before 1900	0.821**	
	(3.21)	
Richer than reference group	-0.282***	0.124***
	(-12.06)	(5.82)
Multidimensional poverty index	1.483***	-1.092***
	(13.57)	(-10.54)
Adjusted Energy Povery Index		-0.655***
		(-6.40)
Controls		
Personal	Yes	Yes
Education	Yes	Yes
Work	Yes	Yes
Dwelling	Yes	Yes
AIC	122899.7	
BIC	123857.9	
ll	-61330.9	
Observations	23193	

t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Determinants of satisfaction jointly estimated with the determinants of being energy poor. AEH2 is the EP adjusted headcount ratio. SWB is the satisfaction question. Dwelling's construction ancientness includes 8 dummies, one for each class. The reference class is "2013-2010". Richer than reference group takes 1 when the individual equivalized income is greater than the reference group income. Multidimensional poverty index is constructed using the same methodology of our EP index; it contains 23 material and social deprivations. It has been run a bivariate ordered probit estimation clustered at the family level. Personal contains socio-economic individual characteristics. Education includes controls for the highest reached ISCED level. Work groups the employment status. Dwelling includes information about urbanisation degree, number of rooms avaible, type of dwelling fix effect, region fixed effect

To understand the impact of EP on different levels of SWB, we have computed the marginal effect of a change in energy poverty intensity, referring to the specification in table 5. Table 7 reports the average partial effects of our EP index on SWB. All the AMEs report a negative effect on the probability of remaining at the set level of satisfaction. For low levels of satisfaction, the effect is stronger; the same applies to severity. By contrast, for a higher level of satisfaction, the severity seems less concerning than being in energy poverty per se. We can conclude that the more satisfied people are, the less they care about being in energy poverty. It is likely that people who are experiencing a high level of utility do not consider energy poverty to be an issue. Therefore, our findings seem to highlight myopic individual declared preferences regarding health and social problems related to energy poverty.

Table 6: *Average Marginal Effect of Energy Poverty on Subjective well-being*

Pr(SWB,EP)	AME	Std.Err.	P>z	[95% Conf.Interval]	
Panel A: AEH2 # 1 → #2					
SWB#1	-0,040	-6,13	0,000	-0,053	-0,027
SWB#6	-0,052	-6,71	0,000	-0,068	-0,037
SWB#7	-0,031	-5,5	0,000	-0,042	-0,019
SWB#10	-0,001	-2,920	0,004	-0,001	-0,00018
Panel B: AEH2 #4 → # 5					
SWB#1	-0,051	-5,87	0,000	-0,068	-0,034
SWB#6	-0,042	-7,26	0,000	-0,053	-0,030
SWB#7	-0,020	-5,77	0,000	-0,027	-0,013
SWB#10	-0,0002	-2,8300	0,0050	-0,0003	-0,0001
Panel C: AEH2 #5 → # 6					
SWB#1	-0,056	-5,91	0,000	-0,075	-0,037
SWB#6	-0,040	-7,46	0,000	-0,050	-0,029
SWB#7	-0,017	-5,67	0,000	-0,024	-0,011
SWB#10	-0,0001	-2,6600	0,0080	-0,0003	-0,00004

SWB#: fixed level (Prob to stay at least in #) ; AEH # → #: level change

Table 3 in the Appendix reports the estimation of the simultaneous system using the affordability measure instead of our adjusted energy poverty index, with both specifications of the instrument. The set of dummy has low statistical support, and the signs are not coherent with the reference year. When using the single dummy (Before 1970), there is no statistical support. The relative-income position is strongly significant in both of the first equations, meaning that being richer than the reference group decreases the probability to be energy poor. However, the SWB equation shows no significant coefficients, apart from the deprivation index in the second specification. It might be that the relative financial position variable joint with being energy poor measured with the affordability metric is underling collinearity. Therefore, when addressing social policies to detect welfare losses due to energy poverty, the information obtained is sharply improved using the MEPIs.

5.3. Robustness Checks

Our robustness checks include more control to capture potential unobserved heterogeneity and the use of different specification of our MEPI.

Table 7 presents some slightly different specifications of our main model. We introduce a covariate that measures the quality of the dwelling and a job-sector fixed effect. We proxy the quality using the rent value, for those who effectively live in a rented house, and the hypothetical rent value, for those who are the owners of the dwelling; the job-sector is controlled by using the 2-digits ISCO08 classifications. Specification (1) is directly comparable with the model in table 5. The coefficient of our EP index slightly increases, although the increase is negligible. It shows that our main results are robust to the controls. The other coefficients stay stable as well. The statistical support of the dummy set becomes stronger than the specification in table 5. It is likely we are eventually capturing more unobserved heterogeneity. In the specifications (2) and (3), we change the dependent variable. Indeed, they are computed using an index that still includes 6 deprivations but with different thresholds. The coefficients of the energy poverty intensity stay negative and statistically significant.

Table 7: *Full information maximum likelihood*

	(1)		(2)		(3)	
	AEH2	SWB	AEH80	SWB	AEH90	SWB
Dwelling's ancientness:						
2000-2009	0.284		0.0904		0.267	
	(1.51)		(0.65)		(1.25)	
1990-1999	0.274		0.0871		0.284	
	(1.45)		(0.63)		(1.34)	
1980-1989	0.358		0.169		0.365	
	(1.91)		(1.23)		(1.72)	
1970-1979	0.436*		0.213		0.454*	
	(2.33)		(1.55)		(2.15)	
1960-1969	0.463*		0.285*		0.500*	
	(2.47)		(2.08)		(2.36)	
1950-1959	0.598**		0.412**		0.647**	
	(3.19)		(2.98)		(3.05)	
1900-1949	0.699***		0.586***		0.785***	
	(3.73)		(4.25)		(3.71)	
Before 1900	0.880***		0.757***		0.946***	
	(4.66)		(5.45)		(4.45)	
Richer than reference group	-0.229***	0.106***	-0.196***	0.105***	-0.222***	0.100***
	(-10.50)	(6.77)	10.53)	(6.70)	(-9.24)	(6.36)

Multidimensional poverty index	1.472***	-1.158***	1.321***	-1.134***	1.726***	-1.115***
	(14.90)	(-16.22)	(15.78)	(-15.79)	(15.58)	(-15.44)
Adjusted MEP Index		-0.667***		-0.897***		-0.798***
		(-5.59)		(-7.07)		(-6.47)
Controls						
Personal	Yes	Yes	Yes	Yes	Yes	Yes
Education	Yes	Yes	Yes	Yes	Yes	Yes
Dwelling	Yes	Yes	Yes	Yes	Yes	Yes
Work	Yes	Yes	Yes	Yes	Yes	Yes
AIC	106330.4		116440.5		98416.2	
BIC	107930.7		118040.9		100008.7	
ll	-52963.2		-58018.3		-49007.1	
Observations	20384		20384		20384	

t statistics in parenthesesc* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Determinants of satisfaction jointly estimated with the determinants of being energy poor. AEH2, AEH80 and AEH90 are the EP adjusted headcount ratio with different thresholds and weighting scheme. SWB is the satisfaction question. Dwelling's construction ancientness includes 8 dummies, one for each class. Richer than reference group takes 1 when the individual equivalized income is greater than the reference group income. Multidimensional Poverty (MP) index is constructed using the same methodology of our EP index; it contains 23 material and social deprivations. It has been run a bivariate ordered probit estimation clustered at the family level. Personal contains socio-economic individual characteristics. Education includes controls for the highest reached ISCED level. Work groups the employment status and a set of dummies for the ISCO08 code. Dwelling includes information about urbanisation degree, number of rooms avaible, dwelling's quality, type of dwelling fix effect, region fixed effect

We repeated the same exercise using all the indices we report in section 3, to confirm that the predictive power is not all captured by a specific deprivation. For the sake of brevity, in Table 8 we only report the coefficients of interest. It shows that every specification keeps our measure of energy poverty intensity negative correlated and statistically significant.

Table 8: *Coefficient's Sensitivity*

	A1	A2	A3	A4	A5	A6
			PANEL A: d = 5			
k = 80 pct	-0.858***	-0.990***	-1.029***	-0.874***	-1.052***	-0.948***
	(-6.88)	(-7.51)	(-7.83)	(-8.00)	(-8.67)	(-7.17)
k= 90 pct	-0.604***	-0.753***	-0.654***	-0.599***	-0.693***	-0.553***
	(-6.05)	(-6.21)	(-5.68)	(-6.39)	(-6.68)	(-4.97)
			PANEL B: d = 6			
k= 80 pct;	-1.107***	-1.188***	-1.273***	-1.097***	-1.293***	-1.183***
	(-7.60)	(-7.51)	(-8.37)	(-8.57)	(-9.09)	(-7.72)
k= 80 pct;	-0.717***	-0.904***	-0.794***	-0.723***	-0.831***	-0.685***
	(-6.23)	(-6.21)	(-6.17)	(-6.75)	(-7.07)	(-5.40)

t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The coefficients of the intensity index of energy poverty have been estimated using the same specification of Table 7. All the models are estimated using a simultaneous ordered probit. A1-A6 indicate the missing deprivation in the index coefficient, referring to Table 1. k indicates the threshold level; d indicates the number of deprivations used to compute the index. Panel A does not include the affordability measure; Panel B includes the affordability measure EB2.

6. Remarks and conclusion

Our analysis has shown that multidimensional energy poverty measures can be used to combine the explicative power of subjective and objective indicators in identifying the energy poor as well as to improve the analysis of the effect of energy poverty on household and individual welfare losses.

We have defined our measure as a multidimensional index based on the combination of subjective and objective deprivations, which measure the intensity of the inadequacies of the dwellings. When assessing the energy poverty in a deprivation framework, the total share of the poor is wider than when evaluated in a mere affordability framework. Moreover, the difference in counting poor enlarges looking at the quartile decomposition (Figure 1a). The share of energy-poor and the experienced severity decrease when income increases, as expected, but it never goes to zero. Our MEPI has been subsequently used to evaluate the welfare losses due to the exacerbation of the severity of energy poverty in an SWB approach. We have shown that the ordinal nature of both SWB indicators and of MEPI measures can adequately be modelled by means of a bivariate ordered probit model equation system, where the endogeneity due to unobserved factors related to the (common) subjective nature of well-being and energy poverty indicators have been tackled by means of theoretically reasonable and statistically valid exclusion restriction.

Our results confirm the negative effect of energy poverty on individual utility. When changing thresholds or number of deprivations used to calculate the intensity measure, the correlation stays negative and strongly significant. E.g., the probability of keeping the median level of satisfaction (7) increases with the increase of the severity with a range between 3% and 1%. Marginal effects point out that individuals are less concerned about the severity of the energy poverty for a higher level of satisfaction. This effect might suggest that more satisfied people (satisfaction likely arising from other sources) are less aware of the health and social consequences of living in energy poverty.

Our findings provide relevant information for the plan of energy poor supporting policies. The results underline the importance of the identification strategy of energy poor, to avoid the exclusion of an important share of vulnerable individuals from any intervention. Moreover, the empirical evidence of the presence of energy poverty independently from the household wealth suggests the need for promoting responsible behaviour both in terms of energy consumption and care of dwellings. On the one hand, the use of a subjective well-being approach detects social and economic hardship, which helps to avoid the exclusion of frail individuals; on the other hand, it highlights that the individual declared preferences occasionally are myopic (e.g. some people do not care to live on energy poverty conditions). However, the latter does not legitimate the absence of intervention. Instead, it could be necessary to implement policies even when some people could not be aware.

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A. Appendix

Table 2: *Full information maximum likelihood - Dummy Instrument*

	(1)	
	AEH2	SWB
Dwelling's ancientness	0.282***	
	(11.37)	
Richer than reference group	-0.287***	0.134***
	(-12.31)	(5.99)
MP Index	1.491***	-1.140***
	(13.66)	(-10.62)
Adjusted MEP Index		-0.658***
Controls		
		(-6.43)
Personal	Yes	Yes
Education	Yes	Yes
Work	Yes	Yes
Dwelling	Yes	Yes
AIC	123034.6	
BIC	123936.4	
ll	-61405.3	
Observations	23193	

t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Determinants of satisfaction jointly estimated with the determinants of being energy poor. AEH2 is the EP adjusted headcount ratio. SWB is the satisfaction question. Dwelling's ancientness takes 1 if the building has been constructed before 1970. Richer than reference group takes 1 when the individual equivalized income is greater than the reference group income. Multidimensional poverty index is constructed using the same methodology of our EP index; it contains 23 material and social deprivations. It has been run a bivariate ordered probit estimation clustered at the family level. Personal contains socio-economic individual characteristics. Education includes controls for the highest reached ISCED level. Work groups the employment status. Dwelling includes information about urbanisation degree, number of rooms avaible, type of dwelling fix effect, region fixed effect

Table 3: *Full information maximum likelihood - Affordability measure*

	(1)		(2)	
	EB2	SWB	EB2	SWB
Dwelling's ancientness:				
2013-2010	-0.241			
	(-0.93)			
2000-2009	-0.0539			
	(-0.61)			

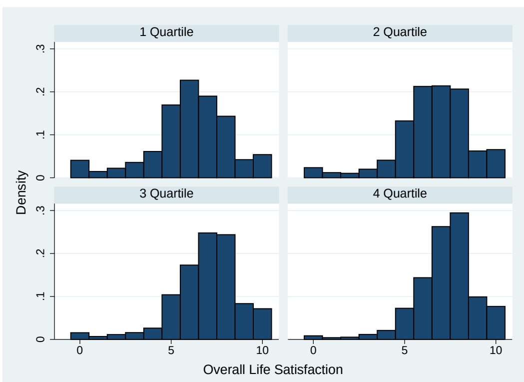
1990-1999	0.00485			
	(0.10)			
1980-1989	0.0189			
	(0.39)			
1970-1979	0.0454			
	(1.12)			
1960-1969	-0.00878			
	(-0.16)			
1950-1959	0.114*			
	(2.57)			
1900-1949	0.117*			
	(2.00)			
Dwelling's ancientness - dummy			0.0756	
			(1.72)	
Richer than reference group	-1.354***	-0.713	-1.355***	-0.238
	(-16.64)	(-1.79)	(-16.69)	(-0.71)
MP Index	0.528**	-0.648	0.527**	-1.035***
	(2.65)	(-1.55)	(2.65)	(-4.48)
Being energy poor		-0.102		-0.126
		(-1.24)		(-1.40)
Controls				
Personal	Yes	Yes	Yes	Yes
Education	Yes	Yes	Yes	Yes
Work	Yes	Yes	Yes	Yes
Dwelling	Yes	Yes	Yes	Yes
AIC	93594.7		93621.8	
BIC	94512.6		94483.3	
ll	-46683.4		-46703.9	
Observations	23193		23193	

t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

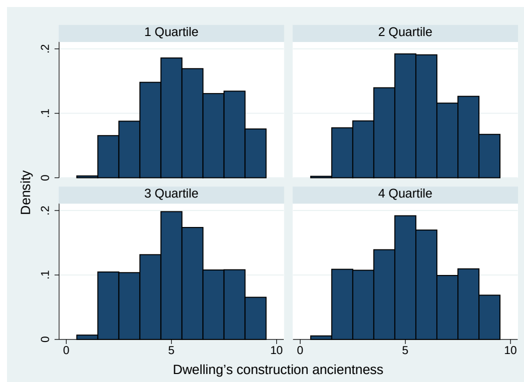
Determinants of satisfaction jointly estimated with the determinants of being energy poor. EB2 is the affordability index, the modified 10% Rule, which sets a double threshold on the income share spent in electricity and fuel consumption, respectevely of 10% and 5%. SWB is the satisfaction question. Dwelling's construction ancientness includes 8 dummies, one for each class. The reference class is "before 1900". The second specification use a dummy that takes 1 if the building has been constructed before 1970. Number of the available rooms counts the rooms available to the household. Richer than reference group takes 1 when the individual equivalised income is greater than the reference group income. Multidimensional poverty (MP) index is constructed using the same methodology of our EP index; it contains 23 material and social deprivations. It has been run a bivariate ordered probit estimation clustered at the family level. Personal contains socio-economic individual characteristics. Education includes controls for the highest reached ISCED level. Work groups the employment status. Urban includes information about urbanisation degree, type of dwelling, region fixed effect.

Table 1: *Summary statistics*

Variable	Mean	Std. Dev.	N
Male	0.46	0.5	24133
Age	54.73	16.49	24133
Self-assess health1	0.1	0.3	23518
Self-assess health2	0.53	0.5	23518
Self-assess health3	0.25	0.43	23518
Self-assess health4	0.1	0.3	23518
Self-assess health5	0.02	0.15	23518
Married	0.61	0.49	24133
Separated	0.04	0.19	24133
Divorced	0.03	0.18	24133
Never married	0.2	0.4	24133
Widowed	0.12	0.33	24133
Children	0.23	0.42	24133
Pre-Primary	0.03	0.16	23846
Primary	0.19	0.39	23846
Low-secondary	0.26	0.44	23846
Upper-secondary	0.36	0.48	23846
Post-secondary	0.03	0.18	23846
Firs-tertiary	0.13	0.34	23846
Employed	0.32	0.47	24133
Unemployed	0.07	0.25	24133
Self-employed	0.11	0.31	24133
Retired	0.29	0.45	24133
Equivalised Income	19444.51	14701.44	24133
Richer than reference group	0.41	0.49	24133
Material deprivation	0.14	0.11	24133
Flat	0.48	0.5	24089
N. of rooms	3.41	1.1	24133
Owner	0.78	0.41	24133
No-urban area	0.62	0.49	24133
Dwelling quality	551.24	286.07	24133
Dwelling's construction 2013-2010	0.00	0.07	24133
Dwelling's construction 2000-2009	0.09	0.28	24133
Dwelling's construction 1990-1999	0.1	0.3	24133
Dwelling's construction 1980-1989	0.14	0.35	24133
Dwelling's construction 1970-1979	0.19	0.39	24133
Dwelling's construction 1960-1969	0.18	0.38	24133
Dwelling's construction 1950-1959	0.11	0.32	24133
Dwelling's construction 1900-1949	0.12	0.32	24133
Dwelling's construction before 1900	0.07	0.25	24133
Dwelling's construction before 1970 - dummy	0.48	0.50	24133



(a)



(b)

Figure 1: *The histograms report the overall satisfaction and the year classes of the building construction distributions by income quartiles.*