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A Stochastic Model for energy poverty analysis

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ABSTRACT

So far, the lack of a common, effective way of measuring energy poverty has been detected as a major weakness in handling the energy poverty problem. One of the main causes has been the complexity of modeling the "required energy consumption" of households, as demanded by the official 10% indicator, and its replacement in calculations by the "actual energy consumption", which, as is well known, underestimates the real needs of households. This weakness is addressed in this paper, through the development of the "Stochastic Model of Energy Poverty" (SMEP). The development of the model includes, firstly, the modeling of energy consumption at household level and, subsequently, the transition from household level to country level through stochastic analysis (Monte-Carlo simulation). Through Sensitivity Analysis, the impact of various parameters on energy poverty is quantified for the first time, by determining their weighting factors. Applied to the case of Greece, it is found that energy poverty reaches 70.4%, with income being the decisive factor affecting energy poverty at 63%, while other variables (H_{tot}, etc.) follow at significantly lower percentages. The findings can be used in order to assess in advance the effectiveness of energy poverty measures, making the model a valuable policy tool.

1. Introduction

Energy/fuel poverty is one of the biggest challenges of the 21st century. Despite the rapid scientific and technological development of the modern world, quality of life does not follow the same pace. More and more households have difficulty meeting their energy needs, a situation expressed either by inability to pay energy bills or by limited access to energy and inadequate energy services. This trend mainly arises as a consequence of low incomes, high cost of energy and energy inefficiency of residences (Legendre and Ricci, 2015; BPIE, 2014; Palmer et al., 2008; IEA, 2011). Especially in Europe, austerity policies imposed by governments, as a result of the broader economic crisis, have placed energy poverty on the top of national problems, with various social, economic, political, environmental and health implications.

It has been assessed that energy poverty in Europe affects between 50 and 125 million people (EPEE, 2009b), while it has been noted that energy poverty rates vary significantly across different Member States (BPIE, 2014). Actually, Bouzarovski and Tirado Herrero (2017) reported that energy poverty incidence is considerably higher in Southern and Eastern EU Member States. Unfortunately, an accurate assessment of the extent of the problem at European level is impeded by the absence of a common European definition (Thomson et al., 2016), as well as by the scarcity of suitable data across Europe (Thomson et al., 2017).

The problem has become even more acute in Greece since 2009 (the outburst of the economic crisis), with fuel prices noting a remarkable rise, up to 90.16% for heating oil between 2009 and 2014 (Ministry of Infrastructure, Transport and Networks, 2009, 2014) and, conversely, with average annual income marking a drastic reduction, by 29.10% at the same period (Hellenic Statistical Authority, 2012a, 2016a). Actually, Greece is currently one of the leading countries experiencing energy poverty in Europe, with some of the highest recorded values in self-reported indicators (inability to keep home adequately warm, arrears on energy bills and dwellings with leakages-damp walls). According to the latest findings, 58% of Greek households are energy poor, spending more than 10% of their income on energy expenses (Papada and Kaliampakos, 2016a). It is noteworthy that mountainous populations of the country are burdened with higher energy costs, while also have lower annual incomes (Katsoulakos and Kaliampakos, 2016; Papada and Kaliampakos, 2015; Katsoulakos et al., 2014), circumstances that have raised the energy poverty rate to 73.5% in the Greek mountainous zone (Papada and Kaliampakos, 2017, 2016b).

In fact, as far as measurement of energy poverty is concerned, there is a large debate within the scientific community. Among the various methods measuring energy poverty, i.e. the objective, expenditure-based measurement guided by the 10% rule (DECC, 2015), the use of subjective indicators (e.g. Bouzarovski-Buzar, 2011) and the broader notion of energy vulnerability (e.g. Bouzarovski, 2014; Middlemiss and

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Gillard, 2015; Bouzarovski and Petrova, 2015; Thomson et al., 2017), the first, quantitative method is still the prevalent one for measuring energy poverty in Europe. According to the official definition adopted by the UK, Energy Poverty Ratio (EPR) is mathematically defined as follows (DECC, 2015):

$$\text{Energy Poverty Ratio} = \frac{\text{Modelled fuel costs(i. e. modelled consumption} \times \text{price)}}{\text{Income}} > 10\% \tag{1}$$

In other words, a household is regarded as energy poor if it is required to spend over 10% of its income on all domestic energy use (heating, domestic hot water, cooking, lighting and electrical appliances) (DECC, 2009), in order to achieve a satisfactory level of warmth, which is defined at 21 °C in the living room and 18 °C in the rest of the house.

In general, the 10% indicator is widely used and has been established as the typical indicator for measuring energy poverty within a country or a region (Atsalis et al., 2016). However, the difficulty of modeling/calculating required energy consumption, as demanded by the official definition, has led the vast majority of the scientific community to an easier, apparently similar but misleading solution: the use of actual energy consumption in calculations. This happens because the collection of "actual consumption" data is feasible through annual national statistics or through primary surveys, while the modeling of required consumption is a particularly complex procedure. Indicatively, it has been reported that energy consumption modeling is almost an exclusive privilege of the UK, which has developed a special calculation program of the required consumption per household, the BRE Domestic Energy Model (BREDEM-2012), adapted to the specific conditions of the country and, in fact, no other European country is able to carry out an in depth modeling (Jones et al., 2016). As a result, the energy poverty ratio with the 10% threshold and the use of actual consumption is the one that, unofficially, has been widely established as the conventional, objective indicator of energy poverty at European level (Roberts et al., 2015; EC, 2010).

However, this conventional indicator has been often criticized for underestimating the real dimension of the problem, as it fails to detect households which, due to economic difficulties, reduce energy consumption at home (Dubois, 2012; Fahmy, 2011; Legendre and Ricci, 2015; Thomson, 2013). Hence, it is generally considered a "poor indicator" of energy poverty (Moore, 2012; Liddell et al., 2012). It has also been reported that, as an indicator, it is very "sensitive" to fuel prices variation, compared to the impact of the other two factors (energy consumption, income) (DECC, 2013), which means that price changes are probably those that almost lead the indicator. In this context, it should be clarified that while the main causes of energy poverty are well defined (energy consumption, energy cost, income), the relative weight of each one of them on the overall problem has not been possible to be quantified yet.

As far as the official indicator of 10% and the use of required energy consumption are concerned, it should be noted that the calculation of modelled energy consumption at an individual household scale has been achieved in many countries, so far. What is still missing is a calculation tool of modeling energy consumption -based on objective needs- at national level. More specifically, respective to the English calculation program (BREDEM-2012), which introduces the calculation of all energy uses by using a large number of parameters, i.e. the area of the house, the number of occupants, the characteristics of cooking appliances, etc., is the Greek program of energy efficiency of buildings (KENAK), adopted in 2010 in Greece. Accordingly, this modeling introduces the calculation of energy consumption of a household, taking into account a significant number of parameters, by examining three main energy uses: heating, cooling and domestic hot water. In case, though, that energy consumption needs to be studied at a country level, where there are practically innumerable cases and combinations of building characteristics, heating systems, etc., the use of KENAK (or a similar energy program) as a base study presents a number of inherent limitations:

- Its complicated nature and the large number of input variables considerably hinder the generalization and the stochastic analysis of parameters at country level, increasing, at the same time, the input error.
- While being analytical in terms of building shell characteristics and heating/cooling systems, it makes serious and, even more, controversial assumptions regarding the impact of climate on energy consumption. In particular, the climate impact is only taken into consideration by selecting the respective Climatic Zone, assuming that it remains stable within the zone, which is not the case in reality. Thus, KENAK "neglects" or underestimates the strong impact of climate on dwellings' energy consumption, as its main objective is the estimation of the buildings' energy performance based on their "internal" technical characteristics.

Therefore, the need of developing a model addressing the above weaknesses is obvious. In the present paper, in order to study and analyze energy poverty in Greece, the modeling of energy consumption at national level is attempted. Such a modeling is being endeavored for the first time and is characterized by four main features:

- It is based on the required energy consumption and not on the corresponding actual.
- The method of degree days is selected as the most appropriate method of energy analysis of buildings, as it covers adequately and objectively all the possible aspects (climatic conditions, building shell, heating/cooling systems) of the required energy consumption of a building.
- The technique of stochastic analysis versus deterministic analysis is selected as analysis method, as the values of parameters (and subparameters) composing the required energy consumption present such a large dispersion throughout the whole country, that the use of any point-estimate value as representative (average, median, prevailing value) would produce very poor results and a high degree of uncertainty.
- It enables the quantification of the relative importance of the drivers of energy poverty.

2. Methodology and data

2.1. Development of the mathematical model of energy poverty

In order to estimate modelled energy consumption included in Eq. (1), the basic household energy uses in Greece were taken into consideration:

- Space heating
- Space cooling
- Domestic hot water
- Cooking, lighting and electrical devices

It is noted that cooking is almost totally covered by electricity in Greece, thus it is considered as a single use along with lighting and electrical devices. The modeling of energy uses follows the methodology of the BREDEM manual of the UK. More specifically, among the four main energy uses, space heating and cooling are modelled based on the conditions required in order households to achieve an adequate level of thermal/cooling comfort at home, while the rest ones (domestic hot water and cooking - lighting- electrical devices) are based on the typical consumption levels in Greece. In fact, heating and cooling demand mainly depends on technical parameters (climatic conditions and