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The role of the public sector in the mitigation of fuel poverty in Spain (2008–2019): Modeling the contribution of the *Bono Social de Electricidad*

María Cadaval, Rosa Mª Regueiro-Ferreira, Santiago Calvo*

Universidade de Santiago de Compostela, Spain

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ABSTRACT

With the economic growth of recent centuries, energy has become a structural good of prime necessity (Sovacool, 2011). The prevailing productive and economic model has made energy vulnerability, inequality and poverty a palpable reality in Spain. One of the instruments used to address this situation by the Government has been the implementation of the *Bono Social de Electricidad* (BSE) in 2009 based on a discount on the electricity tariff borne by families, *a priori*, with fewer resources. In 2017, the eligibility criteria were revised in such a way that the concept of vulnerable household was redefined. In this paper, through quasi-experimental methods and using the 2008–2011 and 2016–2019 longitudinal sample of the Living Conditions Survey, the effectiveness of this subsidy in reducing fuel poverty is evaluated. The results show that the BSE has not helped to mitigate it, identifying "new typologies of households" energetically poor.

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1. Introduction

Energy is a key variable in the differentiation between economic growth and economic development, because the economic growth of the last two centuries has turned energy into a structural good of prime necessity and a driving force for prosperity[1]. But it has also become a determining factor in poverty, due to its questionable guarantee of supply, unequal access, its environmental impact, even affecting regions of developed countries, etc. Their incorporation in academic and political agendas has evidenced the magnitude of their impact. The European Union seems to have shown a belligerent attitude, with Directives 2009/72/EC and 2009/73/EC on common rules for the internal gas and electricity market, calling on Member States to set criteria for the definition of "vulnerable consumers" from a fuel poverty perspective if the national legislator deems it necessary, and to establish actions in this sense. The recognition of "vulnerability" seems to imply a stage prior to fuel poverty, depending on the impact of inequalities and barriers in access to energy and energy services [2,3], demanding greater precision in its definition, and therefore, in its measurement.

Fuel poverty can be defined as [4]; p.21)[1]:

> A household can be considered to be in fuel poverty when it is unable to pay a sufficient amount of energy for the satisfaction of its domestic needs and/or when it is forced to allocate an excessive part of its income to pay the energy bill of its dwelling.

This definition implies recognizing the condition in which a household is unable to secure a socially and materially needed level of energy services at home [7]. Over time, the definition of fuel poverty has evolved and taken on greater dimension and complexity, as a systemic challenge connected to broader socio-technical and governance infrastructures [8]. The problem of fuel poverty is linked to energy inequality, which shows the differences

* Corresponding author.
E-mail address: santiagocalvo.lopez@usc.es (S. Calvo).

[1] Following [5,6]; throughout of the paper, we prefer to refer to the term fuel poverty rather than fuel poverty, due to a better suitability to the characteristics of a country like Spain.

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in the levels of access to energy globally, and in energy consumption per capita by location [9], showing the energy consumption gap between richer and less wealthy countries [10].

Countries and regions implemented assistance measures, the outcome of which needs to be assessed (1). Parallel to the liberalization of the electricity sector, protection measures were introduced for groups vulnerable to fuel poverty, as most European countries did by means of a Social Voucher. And realizing that the synergies between energy transition and fuel poverty alleviation requires planned actions, specific goals, measures, and guarantees [11]. There are studies that show that although heating subsidies and social tariffs help reduce the worst effects of fuel poverty during the winter months, it is no long-term solution to get these households out of fuel poverty [12].

The aim of this article is assessing fuel poverty in Spain on the basis of a multidimensional model (for electricity consumption) and to evaluate the effectiveness of the Bono Social in reducing fuel poverty in Spain, considering the different phases of its application based on the regulatory changes. The novelty of the analysis lies in the joint and comparative assessment of the possible impact of the Bono Social, which has not been carried out before. However, there have been limitations, fundamentally in terms of access to disaggregated statistical data, which would have allowed for a more detailed assessment.

The article is structured as follows: Section 2 presents a compilation of the most relevant scientific contributions in relation to the objective of the research. The methodology and data used are described in section 3. The main results and their discussion are the focus of attention in section 4, ending with conclusions and recommendations for policymakers in section 5.

2. Literature review

The scientific literature has focused on the study of fuel poverty and its determining factors, using quantitative approaches with indicators of various kinds. The definition of fuel poverty proposed by Tirado-Herrero et al. [4] presents a clear relationship with the habitability comfort of a dwelling, with the total energy consumed in a dwelling [13]. *A priori*, the impact of this variable depends on three conditioning factors [14–16]:

- The price of energy consumed in the household.
- The income level of the household unit.
- The energy efficiency of the dwellings.

The quantification of fuel poverty has been carried out based on three approaches that present theoretical and methodological limitations, partly due to the lack of consensus on the definition and dimension of the concept itself [5]:

- Temperature indicators: they measure the temperature in dwellings to determine, if there is a situation of fuel poverty, by comparing with an established thermal reference value. This method only assesses fuel poverty from the point of view of air conditioning, and not a global use of energy in the home [17].
- Energy expenditure indicators: these focus attention on the energy expenditure made in home. The pioneer was the Ten Percent Rule Indicator (hereafter, TPR) used in the United Kingdom, whereby a household is in fuel poverty "if it is unable to have adequate energy services for less than 10% of its income" [18]. It presents the difficulty of not knowing the energy expenditure required to meet basic needs, but using the energy expenditure incurred, which could lead to an overestimation of fuel poverty [19]. The 2 M indicator also uses a reference threshold that is twice the median of the proportion of household energy expenditure. As disadvantages, to point out the arbitrariness in the selection of the threshold, which measures more inequality and does not meet the requirements of monotocity, indicated by Amartya Sen for the assessment of poverty [13]. The Minimum Income Standard (hereafter, MIS) indicator was developed by Moore [20]; considering the level of income necessary to enjoy an acceptable quality of life, paying more attention to the most vulnerable strata and identifying acceptable living standards for each group analyzed. The Low Income High Cost indicator (hereafter, LHC) was proposed by Hills [21]; which determines that a household is in fuel poverty when its total income is below 60% of the median income of the population, without considering housing expenses (mortgage and rent expenses) and modeled equivalent energy expenditures (estimated expenditure to meet basic energy needs adjusted for the number of household members).
- Consensus approach indicator: this indicator is based on the consensus that essential goods and services are considered essential at the general level of society, the deprivation of which determines the existence of fuel poverty. Developed by Healy and Clinch [22]; it measures fuel poverty based on an indicator composed of three variables: not being able to afford to keep the dwelling at an adequate temperature in the cold months; having had delays in the payment of bills for the maintenance of the main dwelling; and the dwelling having problems of leaks, dampness in walls, floors, ceilings or foundations, or rotting floors, window frames or doors.

In short, one of the most debated issues in the literature is the type of indicator that should be used to define and measure fuel poverty. To summarize, either objective variables are usually employed, based on household income and energy expenditure, or subjective variables, based on individual perceptions. Objective measures of electricity expenditure effort depend on factors such as geographic location or type of housing, so they would not reflect a complete picture of the issue [23]. For this reason, there is evidence that these two indicators, used in a complementary manner, provide more robust estimates [24]. Thus, fuel poverty would have a multidimensional nature [25], in which the criteria considered may have different relative importance and the assignment of weights is an arbitrary process that requires value judgments [26].

There are only two studies that have evaluated the effectiveness of the *Bono Social de Electricidad* in alleviating fuel poverty in Spain. On the one hand, Bagnoli and Bertomeu [27] use as an indicator of fuel poverty in their main estimations a dichotomous variable that would denote whether a household spends in relation to its income twice the median of the country, while García and Tol [28] use subjective variables based on the ability of families to maintain a warm temperature during the winter, the presence of humidity or leaks, and delays in the payment of electricity bills.

Bagnoli and Bertomeu [27] find positive and significant results in reducing fuel poverty (a reduction of 2% of households), in addition to proving the effectiveness in reducing electricity prices in eligible households without a change in the amount consumed, so that total expenditure has decreased. In contrast, García and Tol [28] do not obtain significant coefficients except for bill payment delays, with the opposite sign to that expected.

Although the effect differs depending on the definition of fuel poverty, both papers conclude that the effectiveness of the *Bono Social de Electricidad* is limited as structured in *Real Decreto June 2009* and developed in *Resolución de 26 de junio de 2009, de la Secretaría de Estado de Energía, por la que se determina el procedimiento de puesta en marcha del bono social*. Bearing this in mind, this papers tries to shed some more light by evaluating the change in eligibility criteria established in *Real Decreto 897/2017*, including the

household income level as an additional condition to receive the subsidy. Also, by using different fuel poverty indicators, as shown below, it is tested whether the effect is sensitive to the index used.

3. Methodology and data

Given the limitations found in objective-type indicators, the central estimates of this paper are based on subjective ones[2] [29,32]. From the longitudinal Living Conditions Survey for households, the following aspects are considered: (i) ability to keep the house at an adequate temperature in winter (*Temperature*); (ii) delays in paying utility bills (*Delays*); and (iii) the existence of leaks in the roof or dampness in the walls (*Dampness*). All variables have been re-coded in such a way that if they take the value 1 it denotes a situation of deprivation and 0 otherwise.

The procedure to obtain the poverty indicator is based on the one described by Aristondo and Onaindia [33]; i.e., it follows a two-stage first-row process, which allows us to consider its intensity. We define as n the number of households and k the dimensions taken into account (in this case, $k = 3$). The deprivation matrix $X = (x_{ij})$ has dimension nxk, where x_{ij} is the deprivation value for household i and indicator j, with $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, k(= 3)$. Given the dichotomous nature of the variables defined in the previous paragraph, the deprivation vector for family i is defined by the expression x_i. ε $\{0,1\}^k$. Finally, w is the vector of weights for each dimension considered, which sum to 1, i.e., $w = (w_1, w_2, w_3)$ ε R^k_{++} and $\sum_{j=1}^{k=3} w_j = 1$.

Next, two poverty indicators are calculated: d_i and p_m. The former takes into account the degree of poverty of the household i, and the latter is a poverty indicator based on a threshold set at m. d_i is the sum of the weighted deprivation variables for each household, and is formally defined by $d_i = \sum_{j=1}^{k=3} w_j x_{ij}$ d_i may take discrete values between 0 and 1. On the other hand, a threshold $m(0 < m \leq 1)$ is set for the d_i values, which identifies a household as fuel poor if $d_i \geq m$, i.e., $p_m(d_i) = 1$, for all other cases $p_m(d_i) = 0$.

The weighting chosen is equal to that used by Bouzarovski and Tirado-Herrero [34]; who weight by 0.5 the variable *Temperature*, and 0.25 the variable *Delays* and *Dampness*. The threshold chosen to identify a household as poor is $m = 0.5$, so that, at a minimum, a household is fuel poor if it has deficiencies in the *Temperature* variable, or jointly in the *Delays* and *Dampness* variables.

For robustness purposes and to take into account the multidimensional nature of fuel poverty, objective variables are also considered. According to Romero et al. [13]; the most appropriate index for the Spanish case is the one based on the Minimum Income Standard (*MIS*), which they define as "the minimum income of a household that allows its members to opt for opportunities and choices that, in turn, enable them to actively integrate into society" (p. 27). Thus, the following inequality would denote a fuel poor household:

$$HI - HC - MIS < FE \tag{1}$$

where *HI* is the net household income, *HC* is the housing costs and *FE* household fuel expenditure. The main problem is to define the *MIS*. Romero et al. [13] consider minimum insertion incomes adjusted to household size and composition according to the OECD equivalence. To calculate a fuel poverty index and a poverty indicator as in the previous case and to take into account the specific consumption of each family, we opted to use the index proposed by Llorca et al. [24]; Rodriguez-Alvarez et al. [35]. More specifically, understanding the *MIS* as the income necessary to cover the minimum needs of households, this includes fuel expenditure, so we subtract the average household fuel expenditure (*AHFE*) for each autonomous community calculated from the Household Budget Survey, and add the specific household fuel expenditure (*SHFE*),[3] to reflect the specific needs of each family. Finally, it is divided by net disposable income:

$$FP = \frac{MIS - AHFE + SHFE}{Netdisposableincome} \tag{2}$$

from equation (2) we obtain the fuel poverty index based on household expenditure and income. The higher the ratio, the higher the intensity of household fuel poverty. Likewise, we define the dichotomous fuel poverty variable from the fraction, denoted as poor households for which $PE > 1$, giving a value of 1, and 0 otherwise.

The fuel poverty indicators used represent one of the main contributions to the literature. First, by using both subjective and objective indicators, we bear in mind the multidimensional nature of fuel poverty, as do papers such as Waddams Price et al. [36]. Second, in addition to categorizing fuel poverty through a dichotomous variable, we consider its intensity, as has been used in other studies for Spain [37] and other countries with a different institutional and economic development environment [38]. This allows us not only to measure the effectiveness of the Bono Social de Electricidad, but also the degree of its success. Finally, we make use of surveys and variables that are widely available in other developed countries, which allows us to develop future research comparing the effectiveness of other similar policies applied, as shown in Table 1 (see Table 3) (see Table 2).

Control variables are introduced to observe both other explanatory factors of fuel poverty and to isolate the effect of the *Bono Social de Electricidad* as described in the following table. Specifically, electricity consumption and fuel poverty can be affected by the age of the dwelling; the number of members composing the household unit and their average age; the annual income; the gender and educational level of the household head; whether the dwelling is located in a rural or urban setting, whether it is set in a building or is detached type, and the region where it is based [37,39–44].

The source of the data is the Living Conditions Survey, published annually by the *Instituto Nacional de Estadística*. More specifically, we use the longitudinal panels of 2008–2011 and 2016–2019, which allow us to count for each period with 2 years of pre-treatment and 2 years of treatment. Being rotating samples, we only allow to remain those families that are interviewed throughout the four years.

3.1. Model construction

We define vulnerable population and, therefore, the population subject to treatment as defined in *Real Decreto 897/2017*. That is,

[2] Nor do these types of variables escape the usual problems related to surveys based on the perception of the people surveyed. Still, they accept better international comparison and adjust better to changes in household needs and experiences [29–31].

[3] Unfortunately, the Living Conditions Survey does not offer reliable information on disaggregated data on household energy expenditure. To obtain this data we proceed as follows: first, from the Household Budget Survey we obtain the proportion that household energy expenditure by autonomous community and year represents of total expenditure on supplies; second, we apply this percentage differentiated by region and year to each household to the variable of expenditure on supplies available in the Living Conditions Survey.

Table 1
Measures to alleviate fuel poverty. Comparative policy.

Germany	- Social voucher applicable to households under social exclusion criteria (income <12,000 euros weighted by family situation). - Fixed annual subsidy depending on the number of household members.
Belgium	- Customers protected by a special tariff, reviewable twice a year. - Form of aid: regional or federal, with subcategories and not cumulative with each other.
France	– 2 Social tariffs: First Need Tariff (TPN) and Special Solidarity Tariff (TSS) for electricity and gas respectively. - Consumers in a situation of vulnerability are those who have this situation recognized and are beneficiaries of special aid such as the CMU-C (*Couverture Maladie UniverselleComplementaire*), or the ACS (*Aide pour una Complementaire de Santé*), with a maximum income limit per household. - Other types of aid such as the Energy Voucher, with a wider scope of action and covering not only consumption but also investment in energy efficiency.
Greece	- Social bonus for families with incomes below 12,000 euros discount on the bill up to 42% per year, charged to the general budget.
Italy	- There is the *bonus sociale* since 2016 offered by all companies as a discount on the annual cost of electricity (20%) and gas (15%). - It is granted according to economic (7500 euros/year), family and dependency criteria.
Portugal	- *Bono Social Dual* for gas and electricity on a common tariff calculated by OMIE. - Discount on bill over 30%, conditioned by type of consumption and contracted power. – 2 types of aid: Social tariff regulated by national regulator ERSE (20% discount on final price applied to the access toll); ASECE tariff, discount that market traders are obliged to apply and represents an Extraordinary Social Support for Energy Consumption.
Reino Unido	- Liberalized market with support programs for specific groups: Cold Weather Payment — support voucher when the temperature is < 0° for a week—, Winter Fuel Payment — help for the payment of energy bills for the elderly—, Warm House Discount — annual fixed support to help maintain homes at a certain temperature—.

Source: own elaboration.

Table 2
Descriptive statistics of control variables 2008/2011.

Variable	Obs.	Mean	Std. Dev.	Min.	Max	Description
houseage	10,929	21.47	16.00	0	111	Age of home
hhsize	10,991	2.84	1.32	1	12	Number of household members
avgage	10,991	48.41	18.97	13.25	86	Average age of household
income	10,991	30744.37	22443.09	−52130.70	289190.09	Disposable income
lincome	10,940	10.10	.76	2.32	12.58	Log disposable income
sex	10,991	.62	.49	0	1	Gender of head of household (% men)
higher	10,991	.24	.43	0	1	Higher education of head of household
urban	10,991	.47	.50	0	1	Household in highly populated area
flat	10,991	.60	.49	0	1	housing in a building
nrooms	10,985	4.99	.94	1	6	Number of bedrooms (if 6, >5)

Source: Living Conditions Survey.

Table 3
Descriptive statistics of control variables 2016/2019.

Variable	Obs.	Mean	Std. Dev.	Min.	Max	Description
houseage	8748	24.19	17.12	0	119	Age of home
hhsize	8772	2.65	1.24	1	8	Number of household members
avgage	8772	50.66	18.68	12.33	86	Average age of household
income	8772	29910.73	21887.33	−1161	357333.94	Disposable income
lincome	8740	10.06	.78	1.74	12.79	Log disposable income
sex	8772	.61	.49	0	1	Gender of head of household (% men)
higher	8772	.29	.45	0	1	Higher education of head of household
urban	8772	.47	.50	0	1	Household in highly populated area
flat	8772	.59	.49	0	1	housing in a building
nrooms	8770	4.84	.99	1	6	Number of bedrooms (if 6, >5)

Source: Living Conditions Survey.

those households that meet any of the following conditions[4]:

1. Large families with at least 3 dependent children;
2. Retirees receiving a minimum pension[5];
3. Consumers who have contracted an electrical power of less than 3 kW;
4. The family income shall not exceed the following amounts:

(a) 1.5 times the Public Indicator of Multiple Effects Income (IPREM, for its Spanish acronym) of 14 payments, in the case that there are no minors in the family unit, or it is not part of a family unit.
(b) 2 times the IPREM of 14 payments, in the event that there is a minor in the family unit.
(c) 2.5 times the IPREM of 14 payments if there are two minors in the family unit.

Figs. 1 and 2 show the evolution of households eligible for the *Bono Social de Electricidad* according to the criteria, as opposed to the actual figure offered by the *Comisión Nacional de los Mercados y de la Competencia* (CNMC, for its Spanish acronym). Only in 2009 is there a coincidence between both percentages, at which point a gap

[4] Unfortunately, the Living Conditions Survey does not collect information on whether households receive subsidies from the *Bono Social de Electricidad*, so the identification of households as treated is based on whether they meet the criteria indicated in the text.
[5] See supplementary material for the construction of the identification.

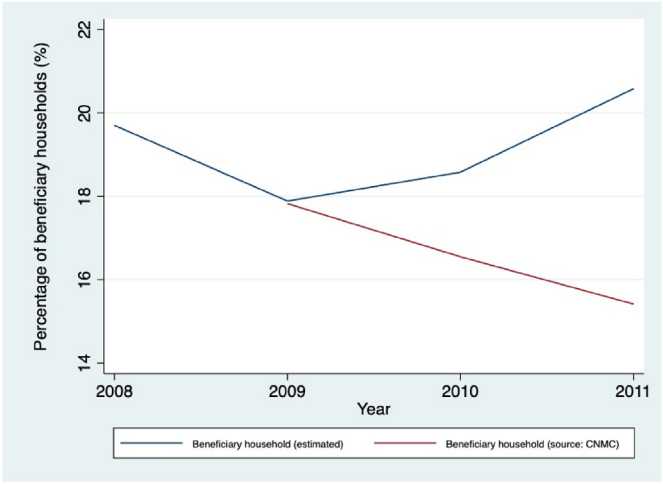

Fig. 1. Percentage of *BSE* beneficiary households, estimated and official 2008/2011. Source: own elaboration from Living Conditions Survey and CNMC.

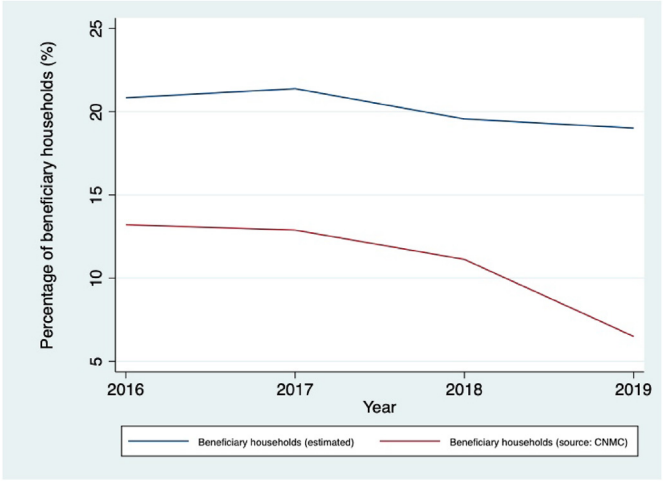

Fig. 2. Percentage of *BSE* beneficiary households, estimated and official 2016/2019. Source: own elaboration from Living Conditions Survey and CNMC.

of between 6 and 7% points widens throughout the sample, and increases considerably as of 2018 due to the changes introduced in the eligibility criteria.[6]

Based on the nature of the policy analyzed, the methodology used is that of difference-in-difference, which is to analyze the causal effect that the *Bono Social de Electricidad* has had on the beneficiary population once it has come into force (2009) and once the change in the definition of the vulnerable population has occurred (2017) in relation to the outcome variable (fuel poverty) with respect to the control group (the population not eligible to receive the Voucher).[7]

In this way, the following regression is estimated using a linear probability model for the case in which fuel poverty is presented as a dichotomous variable; and using a linear model when the dependent variable is a continuous variable that measures the degree of intensity of fuel poverty:

$$Y_{it} = \beta_0 + \beta_1 Treated + \beta_2 Post + \beta_3 Treated{*}Post + \beta_4 X_{it} + \varepsilon_{it} \quad (3)$$

where Y_{it} is the fuel poverty indicator used in each case for the individual i at time t; β_1 is the coefficient indicating the difference between the group of vulnerable and non-vulnerable individuals; β_2 measures the differences over time once the treatment is applied, in this case, the dichotomous variable *Post* takes the value 1 in the years 2010 and 2011, and 2018 and 2019; while it takes the value 0 in the years 2008 and 2009, and 2016 and 2017; β_3 is the difference-in-difference estimator that captures the causal effect of the *Bono Social de Electricidad*; β_4 reflects the effect of the control variables; finally, ε_{it} captures the unobservable factors related to the dependent variable. In order to take into account the possible specif effect of certain regions and years, equation (3) is additionally corrected with a time trend variable and region fixed effects; in a second approximation, the time trend is replaced by time fixed effects; finally, the estimates with fixed effects for each region and year are presented. Standard errors are computed by region and year groups.

The difference-in-difference model assumes parallel trends in the treatment and control groups prior to treatment. That is, in the absence of the *Bono Social de Eelectricidad*, the behavior of the outcome variable should be similar in both groups, since, otherwise, the treatment effect could be biased by being explained by some other variable. A falsification test is formally performed to verify the differences between the treated and control groups between 2008 and 2009 are not statistically significant, if the treatment is applied in 2009. Fig. 3 shows visually that the differences between both groups for subjective and objective fuel poverty dummy between 2008 and 2011 (panels (a) and (c)), while formally confirming the hypothesis of parallel trends for both the number of poor households ($p - value = 0.917$ and 0.331). Between 2016 and 2019 the same result is found ($p - value = 0.318$ and 0.288), representing in panel (b) and (d). Fig. 4 depicts the parallel trends for poverty intensity. It is formally verifies that for the subjective indicators, no significant differences are found before the application of the *Bono Social de Electricidad* in both analyzed panels ($p - value = 0.203$ and 0.984). On the other hand, differences are found for the objective indicator $p - value = 0.09$ and 0.10), but their significance level is low (10%) and in the second period the sign is positive, so that in any case the treatment would be having an effect contrary to that expected.

4. Results and discussion

4.1. Fuel poverty in Spain

Figs. 5 and 6 show the evolution over time in the two samples we used of the 4 fuel poverty indicators defined in the previous section 3. With respect to the fuel poverty dummy, at the beginning of the two periods, the objective indicator is lower, but is more stable over 4 years. In contrast, the subjective indicator detects more households as fuel poor, with a clear rise in the years of the Great Recession (2008 and 2009) and in 2018. In both 2011 and 2019 both types of indices show close values. In terms of poverty intensity, they are not comparable with each other due to their different nature, but interestingly, it can be seen how the dynamics

[6] Note that one of the criteria in force to be eligible for the subsidy in 2009 was to have contracted in the main dwelling a power lower than 3 kW. In December 2017 1.6 million households were receiving the Voucher by this means. This criterion was replaced by another of accessibility, since households that meet the rest of the requirements described in the text should have contracted the Voluntary Price for the Small Consumer (PVPC, for its Spanish acronym), which requires having a contracted power of less than 10 kW. The change in regulations would explain the decrease of 1.1 million beneficiary families.

[7] As indicated by Ref. [27]; since the treated group does not coincide exactly with the households that actually receive the subsidy, the model measures the Intention-to-Treat (ITT) and not the Average Treatment Effect (ATE).

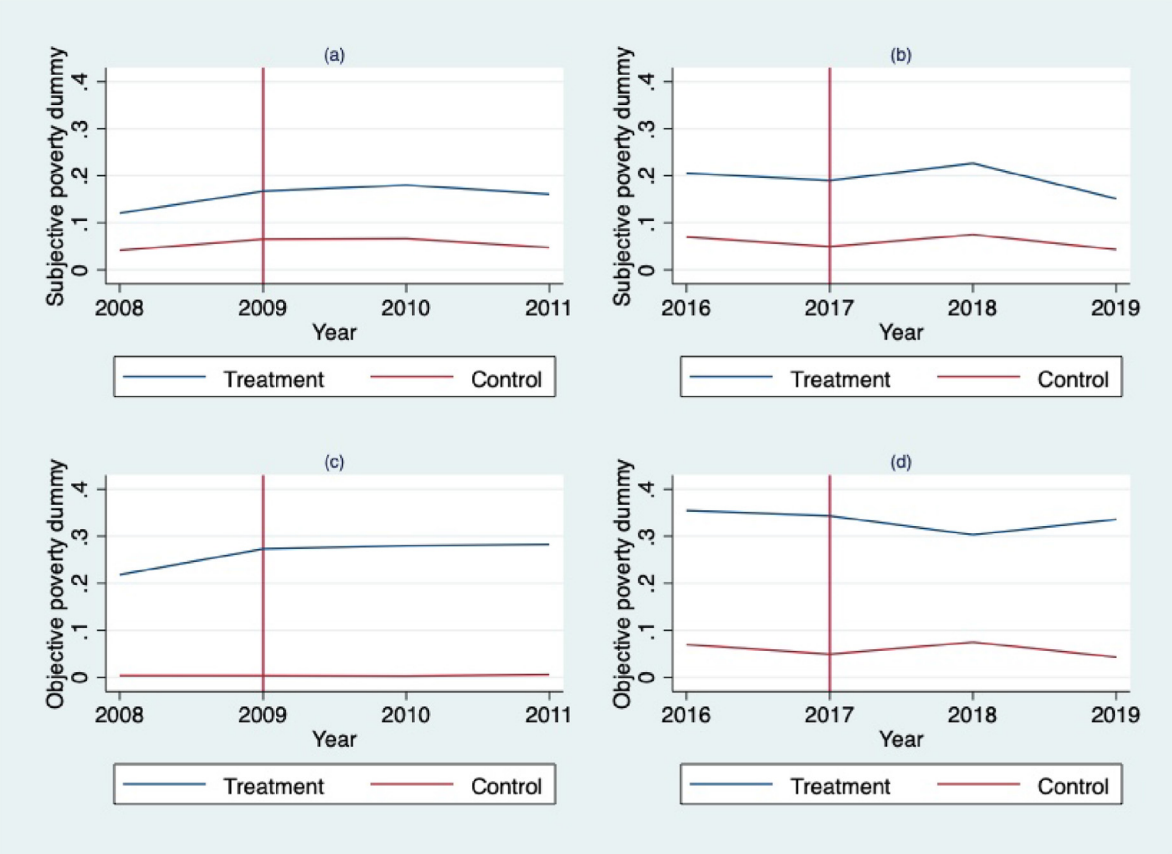

Fig. 3. Parallel trends poverty dummy indicator. Source: own elaboration from Living Conditions Survey.

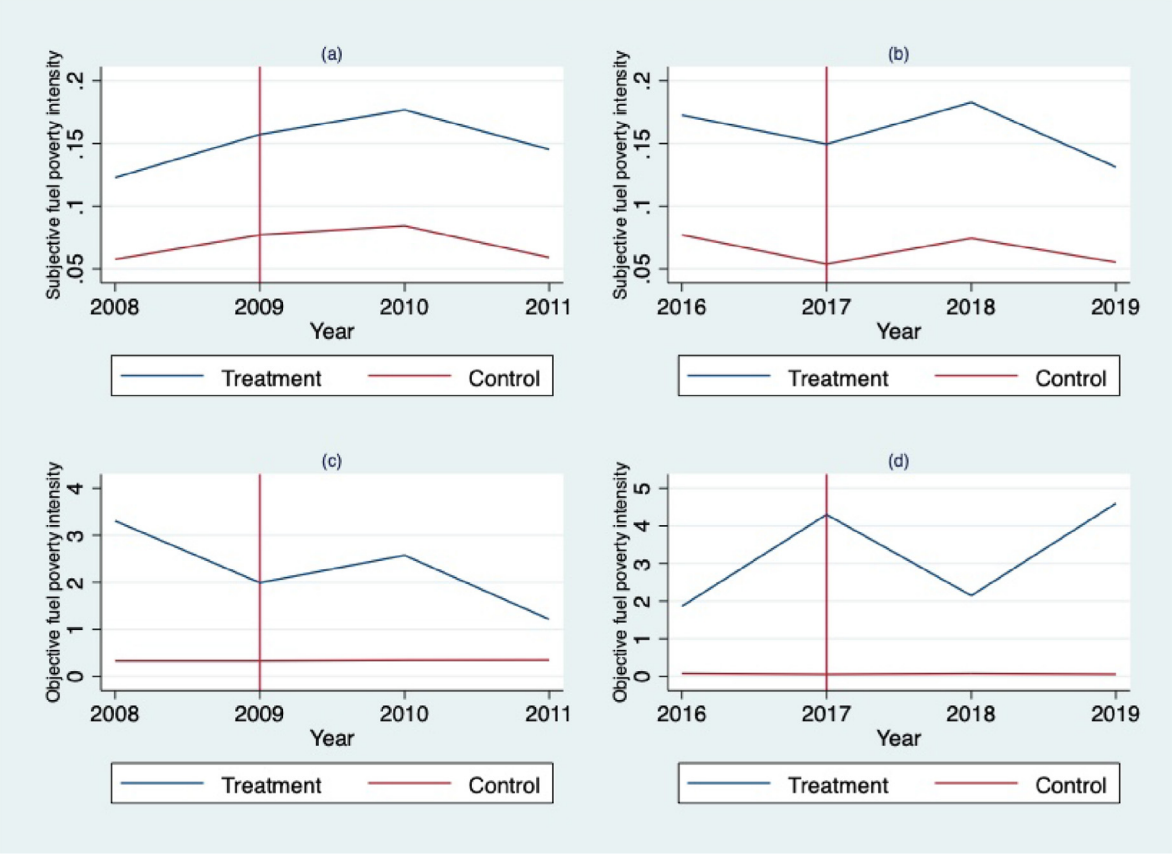

Fig. 4. Parallel trends poverty intensity. Source: own elaboration from Living Conditions Survey.

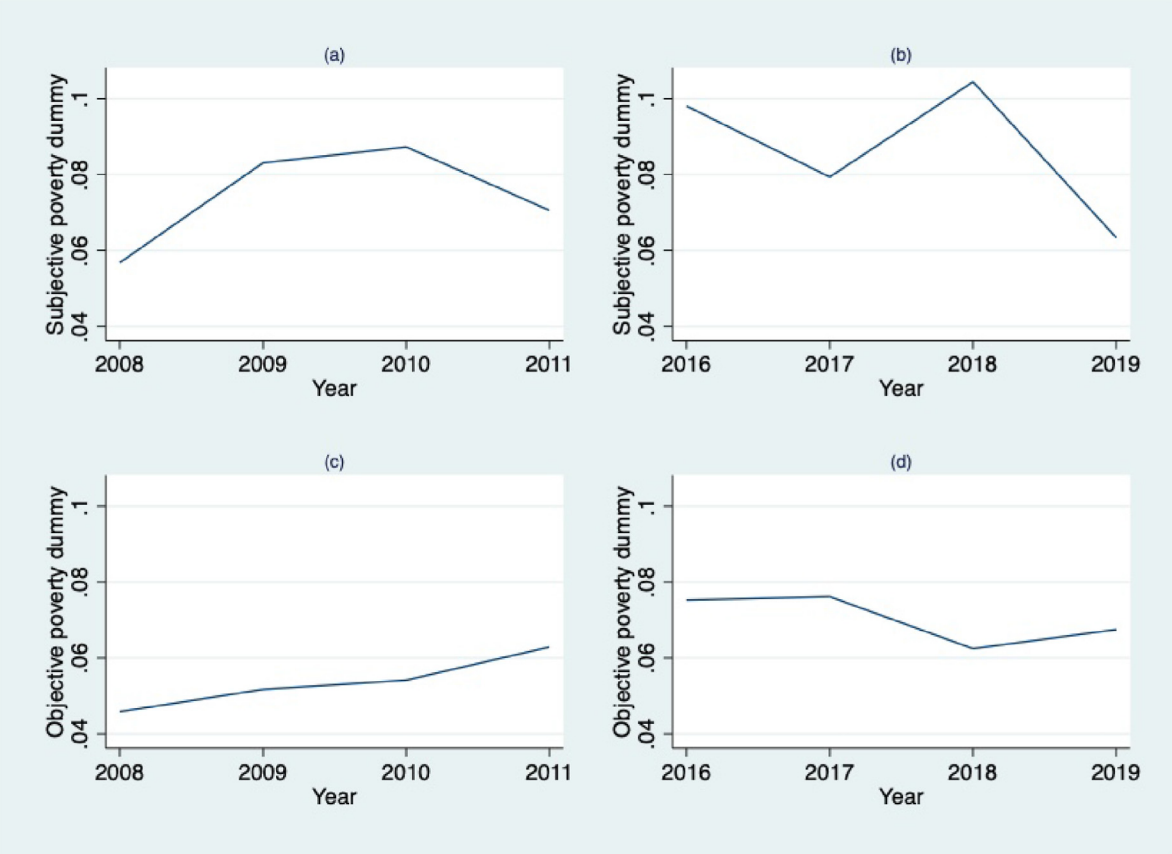

Fig. 5. Households in fuel poverty (poverty dummy). Source: own elaboration from Living Conditions Survey.

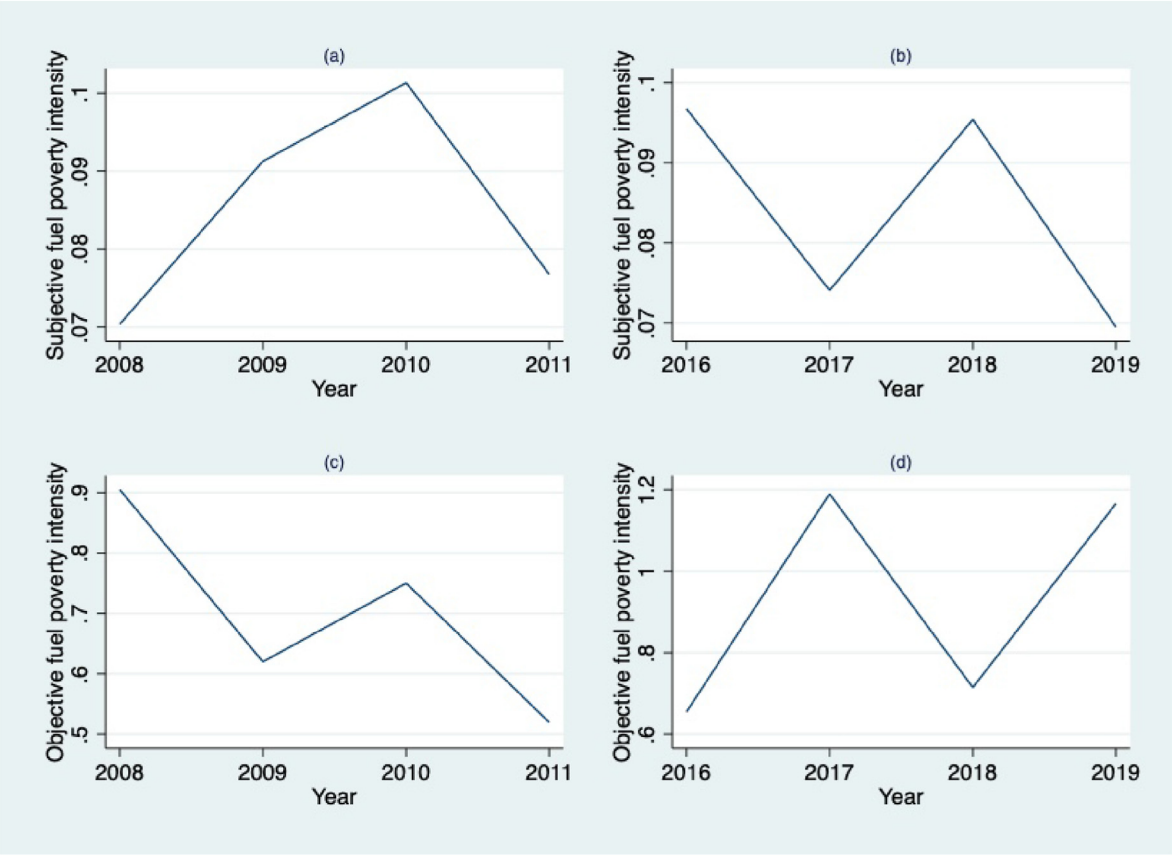

Fig. 6. Fuel poverty intensity. Source: own elaboration from Living Conditions Survey.

Table 4
Estimates dummy indicator subjective fuel poverty, 2016–2019.

	(1)	(2)	(3)	(4)	(5)
treated	0.709***	0.160**	0.146**	0.151**	0.172**
	(12.70)	(2.19)	(2.01)	(2.08)	(2.24)
ttime	−0.007	0.011	−0.202**	0.397***	−0.185***
	(−0.08)	(0.15)	(−2.55)	(3.23)	(−5.06)
did	−0.024	0.018	0.024	0.019	−0.018
	(−0.31)	(0.21)	(0.30)	(0.23)	(−0.22)
houseage		−0.003*	−0.003*	−0.003*	−0.003*
		(−1.71)	(−1.87)	(−1.88)	(−1.75)
hhsize		0.043	0.053*	0.055*	0.053
		(1.40)	(1.68)	(1.74)	(1.62)
avgage		−0.004**	−0.003	−0.003	−0.003
		(−2.04)	(−1.33)	(−1.30)	(−1.39)
lincome		−0.368***	−0.373***	−0.373***	−0.381***
		(−7.34)	(−7.03)	(−7.03)	(−6.96)
sex		−0.088**	−0.095**	−0.097**	−0.099**
		(−2.00)	(−2.21)	(−2.26)	(−2.24)
higher		−0.435***	−0.434***	−0.432***	−0.438***
		(−7.09)	(−7.16)	(−7.15)	(−7.02)
urban		0.017	0.019	0.019	0.021
		(0.28)	(0.32)	(0.33)	(0.35)
flat		−0.014	−0.020	−0.021	−0.021
		(−0.21)	(−0.35)	(−0.36)	(−0.34)
nrooms		−0.120***	−0.116***	−0.116***	−0.115***
		(−4.75)	(−4.88)	(−4.90)	(−4.67)
Constant	−1.559***	3.082***	3.074***	3.293***	3.167***
	(−28.14)	(6.27)	(6.30)	(6.76)	(6.19)
R-squared	0.052	0.108	0.126	0.125	0.144
Observations	8772	8714	8714	8714	8684
Region-FE	*No*	*No*	*Yes*	*Yes*	*No*
Year-FE	*No*	*No*	*Yes*	*No*	*No*
Year Trend	*No*	*No*	*No*	*Yes*	*No*
Region-Year trend	*No*	*No*	*No*	*No*	*Yes*

The t-statistics are shown in parentheses. Standard errors are clustered by region and year.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

are totally opposite. This highlights the importance of using both types of indicators as a complement to the research, to try to capture in a comprehensive way the importance of fuel poverty in Spain.

4.2. Impact of the bono social de electricidad

Tables 4 and 5 show the estimates of our model taking the two subjective fuel poverty indexes as the dependent variable for the period 2016–2019.[8] The variable *did* shows the difference-in-differences estimator, which captures the causal impact of the *Bono Social de Electricidad*. Regardless of the dependent variable used, the policy has no significant impact on mitigating household fuel poverty in Spain, in line with the literature reviewed in the previous section 2. As for the control variables, it should be noted that the families most susceptible to be fuel poor are those formed by members with a lower average age, the most numerous, with a low income level, residing in detached dwellings or with few rooms, and whose head of household is female or has a low level of education.

If we compare the results with García and Tol [28]; who also rely on a subjective measure of fuel poverty, although with a different estimation method, in both cases the difference-in-difference estimator is positively and non-significantly associated with fuel poverty. With respect to the control variables, in both cases the logarithm of income, higher educational level, and the flat variable are negatively and significantly associated with the dependent variable.

Tables 6–7 show the estimates, taking the two objective indicators of fuel poverty and intensity as the dependent variable. Despite their different nature, the results and conclusions are similar to those of the previous model. More specifically, families with a larger number of members, with a lower average age and with a household with more rooms have a higher incidence of fuel poverty, while the opposite happens if they reside in flats, with high incomes and the head of household has higher education.

The results of this model can be compared with Bagnoli and Bertomeu [27]; although bearing in mind that there are important differences between the two papers, i.e., the method for calculating the dependent variable is different, the database and the time sample differ, and the vulnerable population is considered according to the 2009 regulations. Despite these notable differences, we can find some similarities in the results found. Although the treatment has a significant impact on reducing fuel poverty in their model, in both it can be concluded that the effect of the *Bono Social de Electricidad* has a limited effect in reducing fuel poverty. With respect to the control variables, the level of income or that the dwelling is in a flat are negatively associated with fuel poverty, while the opposite is true for the number of rooms in the household. Furthermore, given the goodness of fit of the model, there is also a coincidence in the fact that the regions show different trajectories over time, probably due to the different policies implemented by the autonomous communities.

5. Conclusions and proposals for policymakers

In this paper, we have used a quasi-experimental method, a

[8] the results for the period 2008–2011 are attached in the supplementary material, which do not vary from the most recent sample shown in the main text.

Table 5
Estimates subjective intensity fuel poverty, 2016–2019.

	(1)	(2)	(3)	(4)	(5)
treated	0.095***	0.024**	0.022**	0.022**	0.023**
	(10.63)	(2.53)	(2.38)	(2.38)	(2.42)
ttime	−0.001	0.002	−0.021***	0.046***	−0.013***
	(−0.10)	(0.31)	(−3.08)	(4.17)	(−3.58)
did	−0.003	0.002	0.002	0.002	0.000
	(−0.21)	(0.16)	(0.17)	(0.17)	(0.02)
houseage		0.000	0.000	0.000	0.000
		(0.33)	(0.13)	(0.13)	(0.18)
hhsize		0.007**	0.007***	0.007***	0.007**
		(2.55)	(2.67)	(2.69)	(2.61)
avgage		−0.001***	−0.001***	−0.001***	−0.001***
		(−5.35)	(−4.68)	(−4.68)	(−4.66)
lincome		−0.048***	−0.047***	−0.047***	−0.048***
		(−9.47)	(−9.06)	(−9.07)	(−8.97)
sex		−0.010**	−0.010**	−0.010**	−0.010**
		(−2.29)	(−2.51)	(−2.52)	(−2.60)
higher		−0.034***	−0.033***	−0.033***	−0.033***
		(−7.33)	(−7.19)	(−7.21)	(−7.01)
urban		0.011*	0.010*	0.010*	0.010*
		(1.80)	(1.81)	(1.81)	(1.78)
flat		−0.022***	−0.020***	−0.020***	−0.020***
		(−3.68)	(−3.45)	(−3.45)	(−3.40)
nrooms		−0.012***	−0.011***	−0.011***	−0.010***
		(−4.35)	(−4.33)	(−4.33)	(−4.17)
Constant	0.065***	0.673***	0.670***	0.693***	0.669***
	(12.55)	(14.83)	(14.99)	(15.34)	(14.88)
R-squared	0.042	0.087	0.098	0.098	0.103
Observations	8729	8672	8672	8672	8672
Region-FE	*No*	*No*	*Yes*	*Yes*	*No*
Year-FE	*No*	*No*	*Yes*	*No*	*No*
Year Trend	*No*	*No*	*No*	*Yes*	*No*
Region-Year trend	*No*	*No*	*No*	*No*	*Yes*

The t-statistics are shown in parentheses. Standard errors are clustered by region and year.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

Table 6
Estimates dummy indicator objective fuel poverty, 2016–2019.

	(1)	(2)	(3)	(4)	(5)
treated	2.406***	2.438***	2.520***	2.521***	2.640***
	(16.77)	(16.16)	(16.56)	(16.58)	(17.11)
ttime	0.162	0.163	0.238	0.016	0.198
	(1.03)	(1.02)	(1.30)	(0.09)	(1.14)
did	−0.243	−0.175	−0.177	−0.182	−0.265
	(−1.40)	(−0.99)	(−1.02)	(−1.05)	(−1.41)
houseage		0.000	−0.002	−0.002	−0.002
		(0.19)	(−0.67)	(−0.68)	(−0.70)
hhsize		0.047	0.063*	0.062*	0.061*
		(1.48)	(1.88)	(1.85)	(1.76)
avgage		−0.013***	−0.011***	−0.011***	−0.011***
		(−5.46)	(−4.39)	(−4.41)	(−4.49)
sex		0.064	0.085	0.085	0.084
		(1.00)	(1.27)	(1.27)	(1.20)
higher		−0.212***	−0.258***	−0.259***	−0.260***
		(−3.74)	(−4.39)	(−4.41)	(−4.27)
urban		0.073	0.062	0.063	0.069
		(1.16)	(0.93)	(0.94)	(0.99)
flat		0.049	0.054	0.054	0.050
		(0.72)	(0.77)	(0.76)	(0.69)
nrooms		0.018	0.049	0.049	0.051
		(0.55)	(1.51)	(1.51)	(1.52)
Constant	−2.794***	−2.490***	−2.714***	−2.815***	−2.860***
	(−22.00)	(−8.91)	(−8.86)	(−9.09)	(−9.40)
R-squared	0.423	0.451	0.476	0.476	0.484
Observations	8772	8746	8746	8746	8453
Region-FE	*No*	*No*	*Yes*	*Yes*	*No*
Year-FE	*No*	*No*	*Yes*	*No*	*No*
Year Trend	*No*	*No*	*No*	*Yes*	*No*
Region-Year trend	*No*	*No*	*No*	*No*	*Yes*

The t-statistics are shown in parentheses. Standard errors are clustered by region and year.
Due to convergence problems as it is a great predictor of the dichotomous variable of objective poverty, the logarithm of income has been dropped.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

Table 7
Estimates objective intensity fuel poverty, 2016–2019.

	(1)	(2)	(3)	(4)	(5)
treated	2.752*	−9.355*	−9.411*	−9.411*	−9.332*
	(1.87)	(−1.89)	(−1.89)	(−1.89)	(−1.88)
ttime	0.023	0.234	0.935	−1.177	4.213***
	(1.38)	(0.74)	(1.64)	(−1.58)	(6.86)
did	0.226	0.880	0.999	0.999	0.912
	(0.11)	(0.45)	(0.52)	(0.52)	(0.49)
houseage		0.003	0.000	0.000	0.000
		(0.26)	(0.00)	(0.00)	(0.03)
hhsize		2.068**	2.101**	2.100**	2.088**
		(2.17)	(2.17)	(2.17)	(2.16)
avgage		0.009	0.010	0.010	0.010
		(0.59)	(0.63)	(0.63)	(0.64)
lincome		−10.809**	−11.094**	−11.094**	−11.065**
		(−2.12)	(−2.11)	(−2.11)	(−2.10)
sex		1.078*	1.176*	1.177*	1.184*
		(1.72)	(1.75)	(1.76)	(1.76)
higher		3.675**	3.604**	3.604**	3.610**
		(2.19)	(2.19)	(2.19)	(2.18)
urban		1.735*	1.372	1.372	1.362
		(1.69)	(1.45)	(1.45)	(1.43)
flat		−0.707	−0.966	−0.966	−0.938
		(−1.18)	(−1.29)	(−1.29)	(−1.26)
nrooms		0.539**	0.674**	0.674**	0.692**
		(2.09)	(2.32)	(2.33)	(2.30)
Constant	0.351***	100.605**	101.942**	101.234**	101.279**
	(34.51)	(2.11)	(2.10)	(2.10)	(2.10)
R-squared	0.003	0.082	0.083	0.083	0.082
Observations	8735	8709	8709	8709	8709
Region-FE	*No*	*No*	*Yes*	*Yes*	*No*
Year-FE	*No*	*No*	*Yes*	*No*	*No*
Year Trend	*No*	*No*	*No*	*Yes*	*No*
Region-Year trend	*No*	*No*	*No*	*No*	*Yes*

The t-statistics are shown in parentheses. Standard errors are clustered by region and year.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

two-stage first-row process, which allows us to consider the intensity of fuel poverty, using the 2008–2011 and 2016–2019 longitudinal sample of the Living Conditions Survey, and to know the effectiveness of the *Bono Social de Electricidad* (BSE) in reducing fuel poverty. We applied our model to Spain, trying to identify key explanatory variables and the populations groups experiencing fuel poverty (by using electricity). The problem of fuel poverty is linked to energy inequality, which shows the differences in the levels of access to energy globally, and in energy consumption per capita by location, showing the energy consumption gap between richer and less wealthy countries. And being some of its main conditioning factors the access to energy (quantity and quality), energy consumption and its environmental impact, lifestyle, and mode of production, it is essential to delve into the study of its dimension.

The main conclusions are:

- The BSE has not helped to mitigate fuel poverty, but identifying "new typologies of households" fuel poor.
- The largest number of fuel poor is found in the first quintiles, a figure that has increased throughout the years.[9]
- Fuel poverty is a specific phenomenon that is included within the general poverty and inequality in Spain.
- The existence of multiple drivers of the vulnerability affecting households by using electricity in Spain.

The proposed multidimensional fuel poverty model can be useful for policy-makers searching for a more detailed understanding of the characteristics of energy-poor households and the impact of the measures implemented. The fact that fuel poverty has an income and an energy aspect means that tackling the problem requires complex interventions in different policy areas. It may thus be of interest to focus public debate on factors such as dealing with emergency situations; alleviating the causes of fuel poverty; improve the identification of fuel poor households and the knowledge of fuel poverty inequalities; promote well-being as a key against fuel poverty, and to improve standardization and industrialization in energy performance of buildings and how to pay it by the fuel poor population; developing programs to study and prevent fuel poverty, for example by studying the populations receiving income subsidies or the population at risk of social exclusion. All these actions, measures, and studies must be designed according to the social, economic, and energy characteristics of each region.

[9] Tables with the distribution of fuel poverty by quintiles are available in the supplementary material.

Credit author statement

María Cadaval: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing- Original Draft, Writing – review & editing, Visualization, Supervision, Project administration. **Rosa María Regueiro**: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing- Original Draft, Writing – review & editing, Visualization, Supervision, Project administration. **Santiago Calvo**: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing- Original Draft, Writing- Review & Editing, Visualization, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.energy.2022.124717.

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