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Does cash money solve energy poverty? Assessing the impact of household heating allowances in Spain

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ABSTRACT

Energy poverty could be identified as the inability of households to attain a necessitated level of domestic energy services. Since Boardman's pioneering studies, EU Member States have progressively tackled this issue through both mitigating and structural measures. Among the former are the financial aids that seek to support vulnerable households in paying their heating bills. These widespread measures usually suffer from design problems, which can affect their efficacy. That is precisely what this paper aims to provide: an analysis of the effectiveness of the Thermal Social Allowance (TSA) in one of the Member States (Spain), as well as a proposal to redefine it, i.e. the Thermal Energy Cheque (TEC), to address some of its limitations.

For that purpose, this paper proposes a bottom-up methodology to characterise Spanish households' theoretical expenditures for heating and domestic hot water. Then, the TEC proposal integrates this methodology in the calculation of an energy cheque that would enhance the current TSA policy. Furthermore, an impact assessment is carried out to evaluate the effectiveness of the two measures in reducing winter energy poverty.

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The main findings show that in 2019 the limitations in the design of the TSA led to a reduction of winter energy poverty of only 1%, whereas the implementation of the TEC would reduce it by 11%. Nevertheless, both are costly measures that do not tackle other constituent factors of energy poverty, e.g. low energy efficiency of housing, making them unsuitable as medium-long term policies.

Keywords

Energy poverty, Vulnerable households, Energy expenditure, Residential Sector, Policy evaluation

Abbreviations[2]

[2] AT After Tax

AT	After Tax
BT	Before Tax
CTE	Spanish Technical Code for Building Construction
DHW	Domestic Hot Water
EPOV	EU Energy Poverty Observatory
HDD	Heating Degree Days
IDAE	Spanish Institute for Energy Diversification and Saving
LPG	Liquefied Petroleum Gas
RDL	Royal Decree-Law
RTEE	Required Thermal-Energy Expenditure (heating and DHW)
SNSEP	Spanish National Strategy against Energy Poverty
TEC	Thermal Energy Cheque
TSA	Thermal Social Allowance
VPSC	Voluntary Price for Small Customer
WEP	Winter Energy Poverty

1. Introduction

The UK has led the way on energy poverty, as British research and policy have been pioneering the analysis and tackling of this issue since the early 1990s, being the landmark for many other countries. In the first UK Fuel Poverty Strategy, an energy-poor household was defined as ‘one which needs to spend more than 10% of its income on all fuel use’ (excluded mobility and transport needs) ‘and to heat its home to an adequate standard of warmth’[1]. This definition, derived from the pioneering study of Boardman [2], has been used as the official energy poverty indicator in the UK from 2001 to 2013, when the strategy was revised and a new energy poverty metric was introduced [3]. Since then, several studies have been carried out in the EU, but only few Member States have provided official definitions of energy poverty, as pointed out by the most recent report of the EU Energy Poverty Observatory (EPOV) [4].

There is no consensus on the interpretation of energy poverty, since welfare, energy needs and income level are different among EU countries [4]. However, all energy-poor households share a common problem: ‘the inability to attain a socially and materially necessitated level of domestic energy services’ [5]. The main causes of this social scourge have historically been identified as high energy prices, low income, and low energy efficiency in housing [6]. Besides, as detected by [7], a problem that increases energy vulnerability in households is the lack of knowledge about their energy expenditure and the assistance mechanisms they can access. In the numerous studies carried out in recent years, e.g. [6,8,9], there is a broad consensus in identifying energy poverty as a complex problem that requires an in-depth study covering different topics: (1) the definition of energy poverty and the identification of the most appropriate metrics to quantify it, (2) the characterisation of energy needs and income standards of vulnerable households, (3) the study of measures to be taken to tackle energy poverty, and (4) the implementation of these measures through efficient social and energy policies.

Focusing on thermal energy needs (the most relevant ones in the EU residential sector[3] [10]), vulnerable households tend to use heating or cooling installations sparingly to reduce their energy bills [3], often living in unhealthy conditions [11]. These usually affect the household's wellbeing [12] and health [13]. Heating and cooling thermal-comfort-performance-gaps have been assessed for the Portuguese case-study to identify, on one hand, households who are under-consuming energy due to low income (hidden energy poverty) and, on the other hand, families with a high level of energy consumption ('energy or fuel obesity') [14]. In a different study, the annual heating requirements of Italian households have been calculated (with a regional breakdown) by taking into account the number of municipalities belonging to the different climate zones [15]. That work found that energy poverty in Italy is mainly related to the geographical dimension, thus suggesting a rational basis for planning effective strategies. In the UK, The Building Research Establishment Domestic Energy Model (BREDEM) [16] defined an acceptable level of heating 'in terms of the temperature of a dwelling, the extent to which the dwelling space is heated and the number of hours that the occupants spend within the dwelling and require heating'. A study carried out for the Spanish case proposed a methodology that considers the occupants' ability to adapt to climate, i.e. the adaptive comfort model criterion [17]. On the other hand, a study commissioned from the Spanish Green Building Council and Conama foundation [18] analysed the theoretical energy requirements for residential heating in the various Spanish provinces.

Regarding the overall approach to the issue in Spain, the National Government defined energy poverty as the situation in which a household cannot meet its domestic energy

[3] In EU households, heating and domestic hot water account for 79% of total final energy use [10].

needs ‘as a result of insufficient income and which, in some cases, may be aggravated by energy-inefficient housing’ [19]. In 2019, according to the Ministry for the Ecological Transition [20], 6.6% to 16.7% of the Spanish population (depending on the EU-Energy-Poverty-Observatory’s indicator used [21]), i.e. between 1.2 and 3.1 million households, was facing energy poverty.

In this context, given the multidimensionality of this issue [22], it is necessary to design an integrated strategy that includes both mitigating and structural measures [8]. The first type of measures tackles energy poverty in the short term by helping vulnerable households to pay their bills through financial aids and avoiding cuts and/or maintaining a ‘minimum energy supply’ in vulnerable households. Structural measures, e.g. housing retrofitting interventions, usually take a longer time to be implemented, but they are more effective to avoid ‘chronifying’ energy poverty in the medium-long term [23].

Regarding mitigating measures in Spain, the Royal Decree-Law (RDL) 15/2018 [24] introduced the ‘Thermal Social Allowance’ (TSA), which is a yearly transfer-in-cash for residential thermal uses (heating, DHW, and cooking). This financial aid takes into account differences in climate but does not consider dwelling and household characteristics. Furthermore, the payment amount depends on the national annual budget approved for this purpose, which may vary every year. On this subject, the Spanish National Strategy against Energy Poverty (SNSEP) [19], presented in 2019, pointed out the necessity of an integrated characterisation of domestic energy needs, which might help policymakers to improve energy poverty policies, such as the TSA.

In the European context, financial energy-poverty measures, e.g. the French Energy Voucher, are usually assigned only according to the household’s income level and composition. In this regard, the Spanish TSA policy takes a step forward and considers differences in energy needs depending on the climate zone. Nevertheless, it does not include a proper calculation of the expenditure required to adequately cover these needs.

To fill this gap, the present research work provides a bottom-up methodology[4] for quantifying households' thermal-energy needs (heating and DHW), which is used to propose an enhancement to the current TSA. Thus, this paper proposes the implementation of a Thermal Energy Cheque (TEC), which is a cheque for vulnerable consumers that depends on the household's 'Required Thermal-Energy Expenditure' (RTEE), i.e. the theoretical expenditure required to ensure the indoor environment comfort during winter (heating) and to provide an adequate level of domestic hot water (DHW), considering the following primary parameters: climate zone, basic dwelling's characteristics (typology, size, energy efficiency rate and thermal installations' type) and household size (only for DHW).

Firstly, an analysis with a high geographical resolution (including the assessment of the 'Required Thermal-Energy Demand' for the 8,131 Spanish localities) is carried out to obtain the average provincial RTEE values. Secondly, this paper assesses the potential impact of the TEC policy on vulnerable-households' energy expenditure, according to the RTEE analysis and the Spanish-vulnerable-consumers' classification. Finally, this work presents an analysis of the effectiveness of the current policy (TSA) and the proposed one (TEC) in reducing 'winter energy poverty', i.e. considering only households' heating and DHW expenses.

Briefly, as a novelty of this work, the assessment of the RTEE bridges the gap pointed out in the SNSEP and makes it possible to quantify the household energy expenditure required to guarantee thermal comfort during winter and an adequate supply of DHW

[4]The above-mentioned bottom-up methodology consists of calculating the energy demand of a geographical region from aggregate data at the bottom-levels, e.g. dwelling characteristics.

throughout the year. Then, the TEC proposal integrates the RTEE model in the calculation of an energy cheque that would enhance the current Spanish TSA policy, thus meeting a significant percentage of vulnerable households' winter energy needs. The significance of this work lays on the importance of designing effective measures to support thermal energy costs such as the ones related to heating and DHW. On the one hand, these services account for 59% of the Spanish residential final energy consumption [25]. On the other hand, as mentioned before, vulnerable households tend to use heating installations sparingly to reduce their energy bills, often living in unhealthy conditions. Therefore, it is necessary to accurately design and implement these kinds of policies to improve vulnerable households' health and wellbeing. In that regard, this paper fills two gaps concerning previous studies: on the one hand, it carries out an overall analysis for 'winter thermal requirements' of Spanish households (heating an DHW), which can be adapted to other countries and extended to other domestic energy needs that can be considered as basics (cooling, household appliances, lighting and cooking). On the other hand, it analyses the current policy that subsidizes the thermal energy consumption of vulnerable consumers and proposes an alternative approach that would decrease winter energy poverty in Spain in a more substantial way.

It has to be highlighted that the proposed TEC is a measure that mitigates the financial issues related to energy bills of vulnerable households in the short-term. Nevertheless, it is a costly measure and does not tackle other constituent causes of energy poverty, e.g. low energy efficiency of housing, which excludes it as a medium-long term measure. Therefore, future studies are needed to incorporate this analysis in an integrated policy framework, which should consider structural measures, such as housing retrofitting interventions. Indeed, the impact of these measures could be assessed using the RTEE methodology proposed in this paper.

The structure of the article is as follows. Section 2 presents a brief state of the art of EU response to energy poverty and analyses the mitigating policies implemented in the UK, France, and Spain. Section 3 describes the methodology used to compute the RTEE and its application to the TEC proposal and analyses the TSA and TEC impact on winter energy poverty (WEP). Section 4 presents and discusses the results obtained by applying the proposal to the Spanish vulnerable consumers. Finally, Section 5 points out the conclusions and policy implications of this study.

2. EU regulatory framework and national mitigating measures for three representative European countries

In 2018, around 34 million Europeans (7.6% of the EU population) were unable to afford to keep their homes adequately warm [26]. Two years earlier, the European Commission published the 'Clean Energy for All Europeans package' [27] to promote energy transition in the EU. The document sets the Energy Union as a priority and pursues three main goals: (1) 'Putting energy efficiency first'; (2) 'Achieving global leadership in renewable energies'; (3) 'Providing a fair deal for consumers'. In 2018, the European Commission came to a political agreement with the Council and the European Parliament [28], which sets the targets for energy efficiency (32.5%), renewable energy (32%), greenhouse gas emissions (40% cut compared to 1990 levels) and electricity market for 2030. In 2019, the Council of ministers of the EU defined the remaining sections of the 'Clean energy for all Europeans package' [29]. Two of the main intentions of this package were reducing energy bills and tackling energy poverty.

In this framework, the Regulation (EU) 2018/1999 [30] established several obligations for the Member States' integrated-national-energy-and-climate-plans. Specifically for energy poverty, the EU countries should: (1) asses the number of energy poor; (2) in case of a significant number of energy poor, carry out specific policies and set targets for the reduction of energy poverty in the country; (3) report information on progress towards the national energy-poverty-reduction targets. All this information has to be shared with the EU Energy Poverty Observatory (EPOV). The most recent report of the EPOV on energy poverty polices in Member States was published in 2020 [4]. Furthermore, in the same year, the EU Commission published a Recommendation Document on energy poverty [31], which summarizes the EU legislative framework and points out some guidelines for the analysis [26] and fight against energy poverty.

The following sub-sections analyse the mitigating policies implemented in the UK, France, and Spain. The UK is the first European country that introduced measures to tackle energy poverty, thus, giving its trajectory, it can be considered a good example of consolidated policies; France stands out for its commitment in recent years in the fight against energy poverty [32] and the introduction of an energy voucher for vulnerable households [33], which partially inspired the proposal presented in this paper; Spain is the case study of this article.

2.1 United Kingdom

The UK is the European country that first researched and addressed energy poverty. Since 2001, when the first UK Fuel Poverty Strategy [1] was published, the UK Government has been adopting several policies to tackle this social scourge [34].

Currently, the governments of the four UK countries use different methodologies to estimate the number of energy poor households [35]. However, according to the EPOV estimation, in 2018, 5.4% of British population was unable to keep home adequately warm [21]. The current energy poverty measures to support heating costs in the UK and the corresponding payment for winter 2019/2020 are shown in Table 1 [36].

Measure	**Eligibility**	**Energy supply**	**Administrative level**	**Payment [€[5]] for winter 2019/2020**
Warm Home Discount	-Households with social benefits -Low-income households -Pensioners	Electricity / Gas	National government	€160 (discount on energy bill)
Winter Fuel Payment	-Elderly people	Unspecified	National government	€114 - €342
Cold Weather Payment	-Households with social benefits -Low-income households -Pensioners -Unemployed people -People with disabilities	Unspecified	National government	€28.5 for each 7-day period of very cold weather

Table 1. Current energy poverty measures to support heating costs in the UK [36]

The Warm Home Discount is a one-off reduction in vulnerable households' electricity or gas bills for the winter season. The Winter Fuel Payment is a cash transfer for elderly people to help them paying their heating bills. The Cold Weather Payment is an allowance that beneficiaries receive in case of extreme low temperature.

Summing up the first two 'winter payments', i.e. in case of no extreme-cold weather-conditions, pensioners in the UK get, on average, €388. This amount was enough to cover the average energy poverty gap in England, i.e. 'the reduction in fuel bill that the average fuel poor household needs in order to not be classed as fuel poor', which was estimated at €381 approx. for 2018 [35].

[5] £1 = €1.1402 (https://www.bankofengland.co.uk/boeapps/database/Rates.asp?Travel=NIxAZx&into=GBP), 10th March, 2020.

2.2 France

In 2018, 5% of French population has been unable to keep home adequately warm [21]. France can be taken as a reference in the EU because of its political leverage and its commitment in recent years in the fight against energy poverty [32]. Particularly interesting for the proposal presented later in the paper is the recent introduction of an energy cheque for vulnerable households [33]. The mitigating measures implemented at national level during the last years can be summarised as follows. Between 2004 and 2017, the social tariffs of electricity and gas have been the national financial measures to help low-income households pay their bills. These were discounts on the bill cost related to energy consumption. In 2018, the French Government replaced the social tariffs scheme with the Energy Voucher [37], which is an annual cheque for vulnerable households[6], valid for all domestic energy carriers and assigned according to the income level and the household size. Currently, French vulnerable consumers can use the energy voucher in three different ways: (1) online, in a specific website of the French Ministry for the Ecological Transition [33]; (2) by requesting for an automatic deduction of the voucher amount from their bills; (3) by sending the energy voucher to their supplier by post. The average amount of the Energy Voucher in 2018 was €150, while the French Energy Poverty Observatory [38] estimated that the average energy poverty gap per household would vary from €526 to €735, depending on the method used. The Energy Voucher has been revalued in 2019 by €50 [33] for all beneficiaries, so reaching the total average amount of €200. Nevertheless, as mentioned before, the Energy Voucher is assigned only according to income level and the household size, thus not taking into

[6] The Energy Voucher is not a bank cheque, so it cannot be cashed at a bank or used for expenses others than energy supply ones.

account the climate zone, which was pointed out as one of the main parameters to consider in the analysis of energy poverty in France [38].

2.3 Spain

In 2018, according to the EPOV [21], 9.1% of Spanish population was unable to keep home adequately warm. This share was significantly higher than the British and French ones (both around 5%), and considerably greater than EU average share (7.6%), thus pointing out the vulnerability of Spanish households to winter energy poverty.

Furthermore, the values of energy poverty indicators in this country have been varying without a clear pattern during the last years [20,39], while the public administration has been implementing limited policies to mitigate this issue. For instance, the main measure to tackle energy poverty in Spain until 2018 has been the social tariff for electricity, unlike in the UK or France, where both mitigating and structural measures have been implemented.

In 2009, the Spanish Government, in reception of the European directive 2009/72/EC [40], introduced the first version of the social tariff for electricity [41]. The definition of vulnerable consumer given in the abovementioned law was not income-based and covered only consumers with a contracted power lower than 3 kW. This definition, confirmed in the RDL 13/2012 [42], was modified in 2016. The RDL 7/2016 [43] introduced income and energy consumption thresholds for the social tariff, which vary according to the consumer category (vulnerable, severely vulnerable or at risk of social exclusion) and the household typology (pensioners, large family, etc.). The income-thresholds are the maximum values of the household income acceptable to receive the social tariff. They are based on the Public indicator of Multiple Income (IPREM), which is an index used in Spain as a reference for the granting of aid, subsidies or unemployment benefit. Among the various requirements of the social tariff, it is worth noting that only consumers with the regulated market tariff, i.e. the Voluntary Price for Small Customer (VPSC), can receive the aid. Some recent studies, such as [39], showed that the social tariff for electricity has not improved significantly the comfort condition of Spanish vulnerable households. In 2018 the RDL 15/2018 [24] introduced three main changes: (1) it increased the income and electricity consumption thresholds for the social tariff (see Table A1), (2) it established the need to develop a National Strategy against Energy Poverty, and (3) it introduced a 'Thermal Social Allowance' (TSA).

The TSA is a transfer-in-cash[7] for residential thermal uses such as heating, DHW and cooking. The beneficiaries are the same as for the social electricity tariff, i.e. the vulnerable consumers benefitted from the social tariff 'automatically' (without any additional application required) receive the TSA, and the payment depends on the average winter severity index of the locality ($\overline{\mathrm{WS}}_{\mathrm{locality}}$) and on a coefficient based on the Spanish annual budget approved for this purpose (a), as shown in Eq. (1) [24].

$$\mathrm{TSA}\ [€/\mathrm{year}] = 25 + \mathrm{a} \cdot \frac{\overline{\mathrm{WS}}_{\mathrm{locality}}}{0.115} \quad (1)$$

Eq. (1) calculates the aid amount for vulnerable consumers, which is increased by 60% for severely vulnerable consumers and for the ones at risk of social exclusion. In 2019, the TSA beneficiaries were 1.3 million and €75m of the Spanish annual budget were earmarked for this purpose [44]. This produced allowance amounts for the vulnerable consumers' category of between €25 (mildest climate zone) and €77.5 (coldest climate zone) per household.

[7] The TSA is a deposit in the bank account of the vulnerable consumer, so there is no assurance that the recipient will spend it on thermal energy needs.

In April 2019, the Spanish government approved the National Strategy against Energy Poverty (SNSEP) 2019-2024 [19]. Concerning the focus of this paper, the National Strategy proposed to deeply analyse the energy needs of Spanish households and to enhance the current mitigating measures. Furthermore, the SNSEP estimated the number of energy poor households in Spain (see Section 1 for the most recent data) and set the following energy-poverty reduction targets for 2025: 25% and 50%, respectively, as minimum target and desired target. The indicators analysed in the SNSEP are the ones proposed by the EPOV [21]. Concerning the quantitative indicators, the EPOV proposes two different metrics: the 2M, which quantifies 'the proportion of households whose share of energy expenditure in income is more than twice the national median share', and the M/2, which presents 'the share of households whose absolute energy expenditure is below half the national median'. The latter lacks an income criterion; thus, it systematically includes false positives, e.g. households with low energy-consumption because of high energy efficiency standards in their homes. Instead, several studies, such as [45], proposed a hidden energy poverty (HEP) approach, which takes into account household's income and required energy expenditure.

Although the SNSEP proposed a reform of the TSA to integrate a thermal-energy needs model in the calculation, the allowance formula for 2020 remained the same as the previous year. Furthermore, the number of beneficiaries in 2020 increased due to the extension of the mitigating measures to other social categories [46], introduced by the Spanish Government to alleviate the socio-economic effects of the COVID-19 crisis [47], e.g. the increase of low-income households and the rise of domestic energy demand during the lockdown.

In this context, the proposal presented in this paper provides specific results that could contribute significantly to enhance the TSA policy, thus connecting the analysis of the energy needs of vulnerable households with the design of mitigating policies that efficiently alleviate energy poverty in the short-term. The enhancement of these policies does not preclude that they should be complemented by structural measures in the medium-long term. This is a very relevant issue. Pending a future regulatory development of further measures such as the minimum vital supply, the social tariff for electricity and the TSA are the only mitigating mechanism for energy poverty in the country. This fact highlights the relevant potential of the methodological change proposed in this study.

3. Methodology and data

3.1. Provincial Required Thermal Energy Expenditure

According to the IDAE report on Spanish residential consumption [25], in 2018, the final energy consumption for heating and DHW was 59.4% of the total final domestic energy consumption. Thus, this paper focuses only on ‘winter energy needs’ (heating and DHW), also in accordance with the analysis presented in the SNSEP and the residential thermal uses considered in the TSA policy. Cooking is not considered in this analysis because, in 2018, more than 75% of the Spanish households owned electric cooking appliances compared to 36% who owned gas ones [48]. Furthermore, natural gas consumption during cooking is only 9.5% of the Spanish household’s average natural gas consumption, and therefore has a negligible effect on the thermal energy bill [49]. Thus, in the authors' opinion, this energy consumption should be considered in the electricity needs rather than in the thermal energy ones, as pointed out in previous studies such as [50].

Spain is characterised by a varied climate with an evident difference between the inland and the coast, and cases, such as the Canary Islands, for which ad hoc climate classifications were created. The current official climate-classification was set in the most recent version of the Spanish Technical Code for Building Construction (CTE 2019) [51]. Concerning space heating demand, the winter climate zone is identified by a letter, from A to E, in order of increasing winter severity. The additional letter α is used in Canary Islands to identify the mildest zone (without heating demand). Furthermore, the CTE sets the base temperature for the calculation of the Heating Degree Days (HDD) at 20°C. After processing this basic information (following the methodology established by IDAE [52] and CTE 2019), it is possible to obtain the annual heating demand (referred to the months from October to May, both inclusive) to maintain certain comfort conditions in the house:

17ºC at night and 20ºC during the day[8]. In addition to the heating demand, [53] and the CTE 2019 analyse the thermal demand for the preparation of domestic hot water (DHW). The sum of the energy demands for heating and DHW gives the 'Required Thermal-Energy Demand', which is the theoretical demand required to ensure the indoor environment comfort in winter (heating) and to provide an adequate level of DHW. The heating demand depends on the winter climate zone of the locality and dwelling's characteristics, such as construction-period, typology (block dwelling or single-family house) and size. On the other hand, the demand for the DHW production varies with network water temperature, household size and dwelling typology. The detailed methodology is presented in Appendix B.

In this paper, the winter climate zone of each Spanish locality was identified following the abovementioned regulation (CTE 2019), i.e. depending on the province it belongs to and its altitude with respect to the sea level [54]. Thereafter, the characterisation of the provincial household's Required Thermal Energy Expenditure (RTEE), defined in Section 1, has been carried out according to the following parameters: (a) winter climate zone; (b) network water temperature; (c) household size; (d) dwelling typology (block dwelling or single-family house); (e) dwelling size; (f) dwelling energy-efficiency rate (according to the 'aggregated-construction-period'); (g) type of thermal installations and (h) energy carrier type (shown in Figs. 2 and 3); (i) energy prices and taxes. Fig. 1 shows the overall methodology with the different calculations carried out to estimate the Spanish provincial average values of RTEE.

[8] The specific reference-demand for heating depends on the winter severity index (WS) of the Spanish climate zone considered and on the dwelling typology, as shown in Appendix B.

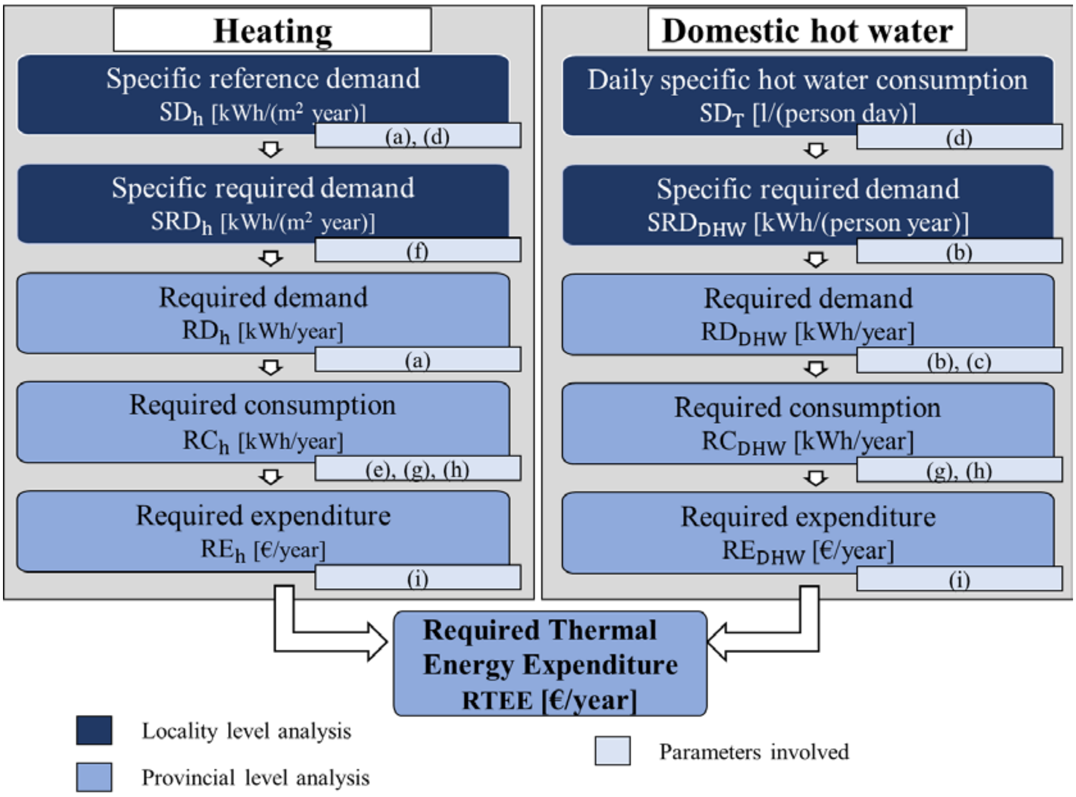

Fig. 1. Flowchart of the Required Thermal Energy Expenditure methodology (the parameters involved in the calculation are listed in the text)

The values of the annual specific required demand for heating (SRD_h, in $kWh/(m^2\ year)$) and the annual specific required demand for DHW (SRD_{DHW}, in $kWh/(person\ year)$) for each one of the 8,131 Spanish localities have been assessed following the procedure explained in Appendix B. Subsequently, a provincial-level analysis has been carried out to aggregate the results and point out some policy implications. A segmentation approach has been applied to the Spanish population to calculate a household's weighted average RTEE for each province. The heating-expenditure clustering has been carried out according to the following parameters: (1a) Aggregated-construction-period; (2a) Dwelling typology; (3a) Type of heating installation; (4a) Heating energy carrier type. On the other hand, the DHW-expenditure segmentation has been performed depending on the following parameters: (1b) Dwelling typology; (2b) Type of DHW installation; (3b) DHW energy carrier type. The derived household-segmentations are shown in Figs. 2 and 3.

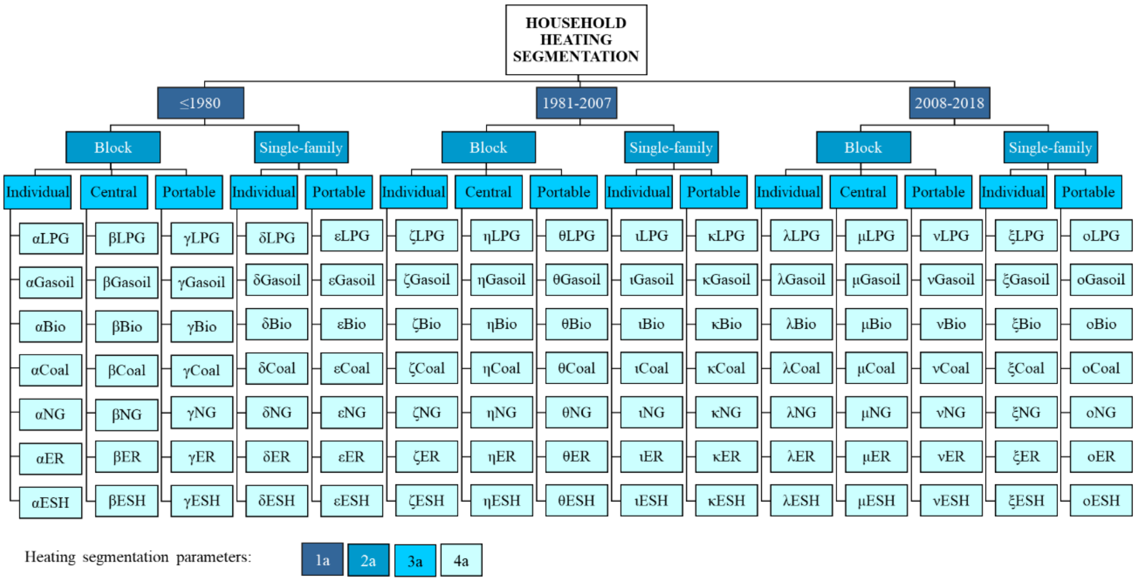

Fig. 2. Household segmentation according to dwelling's heating parameters (Block: block dwelling; Single-family: single-family house; Individual: individual heating system; Central: central heating system; Portable: portable heater; LPG: liquefied petroleum gas (butane/propane); Gasoil: heating gasoil; Bio: biomass; Coal: anthracite coal; NG: natural gas; ER: Electric Radiator; ESH: Electric Storage Heater).

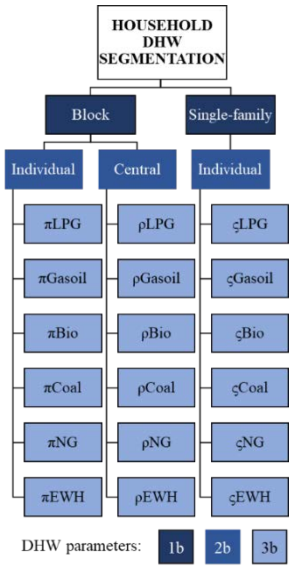

Fig. 3. Household segmentation according to dwelling's DHW parameters (Block: block dwelling; Single-family: single-family house; Individual: individual DHW system; Central: central DHW system; LPG: liquefied petroleum gas (butane/propane); Gasoil: heating gasoil; Bio: biomass; Coal: anthracite coal; NG: natural gas; EWH: electric water heater).

The datasets used for the segmentation of the Spanish population are the following ones:

1. [18], the Spanish Census 2011 [55] and the Spanish Household Budget Survey 2018 [56] were consulted to carry out the clustering related to heating and the parameters (2b) and (3b) of DHW.
2. [57] and [18] were used for the parameter (1b) of the DHW clustering.

The $\mathrm{SRD_j}$ provincial values (where j can be heating or DHW) have been computed by a weighted average of the localities' specific required-demand-values (Eq. (2)[9]), with the population as the weighting parameter.

$$\mathrm{SRD}_{j,k} = \frac{\sum_{i=1}^{n} \mathrm{SRD}_{j,i} \cdot \mathrm{NI}_i}{\sum_{i=1}^{n} \mathrm{NI}_i} \quad (2)$$

Where i is the i-locality of the k-province and $\mathrm{NI_i}$ is the number of inhabitants of the i-locality [58]. This calculation has been repeated for each combination of aggregated-construction-period (only for heating) and dwelling typology for all the provinces. Then, the $\mathrm{SRD_h}$ ($\mathrm{kWh/(m^2\ year)}$) was multiplied by the provincial average dwelling size ($\mathrm{m^2}$) of each combination of the parameters (1a) and (2a) [18] to obtain the household's annual required demand for heating ($\mathrm{RD_h}$, in $\mathrm{kWh/year}$) of each province. Furthermore, an average household size, based on official statistics [58], was assigned to each province, which made it possible to calculate the provincial household's required demand for DHW ($\mathrm{RD_{DHW}}$, in $\mathrm{kWh/year}$). Both demand values are referred to a provincial average household, i.e. a family unit with an average number of persons (used to calculate its DHW demand) that lives in a dwelling with an average size (used to calculate its heating demand).

[9] Note that the weighting of the specific demand by number of inhabitants in each locality of the province is intended to 'weight' the climate zone (in the case of heating) and the network-water-temperature (in the case of DHW) in each province.

Subsequently, the values of annual required consumption for heating ($\mathrm{RC_h}$) and DHW ($\mathrm{RC_{DHW}}$) per Spanish province have been calculated dividing $\mathrm{RD_h}$ and $\mathrm{RD_{DHW}}$ by the seasonal performance factor (SPF) of the dwelling-thermal-installations [52].

Finally, the provincial values of the annual required expenditure for heating ($\mathrm{RE_h}$) and DHW ($\mathrm{RE_{DHW}}$) were estimated by applying the 2019 energy-carriers' prices and taxes (detailed in Appendix C) to, respectively, $\mathrm{RC_h}$ and $\mathrm{RC_{DHW}}$. The sum of $\mathrm{RE_h}$ and $\mathrm{RE_{DHW}}$ gives the provincial weighted average RTEE.

3.2. Thermal Energy Cheque

Currently, as mentioned in Section 2.3, the calculation of the Thermal Social Allowance (TSA) amount in Spain is carried out according to Eq. (1). This paper proposes an enhancement to the current policy, based on a Thermal Energy Cheque (TEC), i.e. a cheque for thermal uses (heating and DHW), which would be calculated for each household according to Eq. (3).

$$\mathrm{TEC}_i \; [€/\mathrm{year}] = \mathrm{f_v} \cdot \mathrm{RTEE}_i \qquad (3)$$

Where i is the i-th household; $\mathrm{f_v}$ is the Vulnerability Level Factor that takes the following values: 25% for vulnerable consumers, 40% for severely vulnerable consumers and 100% for the ones at risk of social exclusion (inspired by the Spanish social-electricity-tariff legislation); RTEE_i is the Required Thermal-Energy Expenditure of i-th household calculated according to the parameters defined in Section 3.1. The correct use of the TEC might be ensured by setting out a cheque processing system similar to the French Energy-Voucher's one (Section 2.2).

Eventually, the application of the proposed TEC policy would require collecting data on the characteristics of each vulnerable family. A household sheet, which would contain the RTEE-parameters listed in Section 3.1 (such as the household location, to identify the climate zone, and basic dwelling's characteristics), might be included in the social aid application to assign the required TEC to each beneficiary. To guarantee the accuracy of the data, the social services and NGOs could help vulnerable households fill out the form correctly.

In this work, the 'annual budget required to implement the proposed TEC policy' has been calculated (see Appendix D) by applying the results of the provincial RTEE analysis to the number of households who benefited from the subsidy in 2019 (identified vulnerable consumers). This data, categorised per province, vulnerability level and household category, was provided by the Spanish Ministry for the Ecological Transition and the National Commission on Markets and Competition in response to two different inquiries [59,60].

With respect to potential changes in energy taxation [61], it is interesting to consider a tax-free scenario for vulnerable consumers and point out the differences with the current outline. Furthermore, a 'before tax' scenario makes it possible to analyse the proposed TEC policy across the Spanish winter climate zones because it eliminates the distortion introduced by the different VAT applied in certain Spanish provinces (see Appendix C). Therefore, two different scenarios of RTEE, and thus of TEC implementation, have been assessed: RTEE after tax (AT) and RTEE before tax (BT).

It should be highlighted that the policy proposed in this document aims to improve the current TSA, but not with the intention of converting it into a medium-long term policy, but as a short-term policy until the implementation of structural measures, such as building retrofit. Indeed, further work could use the proposed methodology to evaluate the impact of energy efficiency measures on the RTEE (from the improvement of the energy efficiency class), and their effect on energy poverty.

3.2.1 Impact on winter energy poverty

This section presents a comparative analysis of the impact of the TSA and the TEC on the proportion of "winter energy poor households"[10] in the 2019 vulnerable-consumers sample, which includes every household who benefited from the TSA policy in 2019 [59]. It should be noted that this analysis does not consider the implementation of other types of energy poverty measures, such as energy retrofit interventions in buildings. The used methodology is inspired by the 2M indicator[11], mentioned in Section 2.3. Thus, this analysis was carried out by calculating the proportion of households whose share of equivalised RTEE in equivalised income is more than twice the M_t, which is the national median share of thermal energy expenditure (heating and DHW) in income. M_t was calculated by applying the methodology presented in [8] to the Spanish Household Budget Survey 2018 (using the data on households' income and actual energy expenditures[12]) On the other hand, the consumers' equivalised RTEE-in-income share was estimated as follows. The RTEE of each consumer cluster corresponds to the provincial average shown in Fig. 4 (RTEE AT) equivalised by using indexes that consider the influence of dwelling's and household's size on heating and DHW needs (adjusting Moore's methodology [3,62] to the Spanish context), and a proxy of the energy-needs' increase due to age (see Appendix E). On the other hand, the consumer-cluster's income

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[10] i.e. considering only their heating and DHW expenses.

[11] In the paper case study, it is not possible to estimate the impact of these measures on hidden energy poverty (HEP) because the actual consumption of the sampled households (vulnerable consumers) is not known.

[12] Households' income were equivalised by considering the number of adults and minors composing the household (OECD modified equivalence scale). In contrast, households' actual expenditures were equivalised according to the household size [8].

was set as the corresponding equivalised income threshold of the social tariff (best-case scenario), which depends on the vulnerability level and the household category (see Table A1). For example, in the first vulnerability level, i.e. 'Vulnerable', the annual income threshold for a household without minors (€11,279) is lower than the threshold set for a household with one minor (€15,039). On the other hand, both thresholds are higher than the ones set for the same household categories in the second vulnerability level ('Severely vulnerable').

Firstly, this $2M_t$ indicator has been estimated for the initial sample, i.e. before the application of the abovementioned measures. Secondly, the impact of the TSA and the proposed TEC (in the scenario 'After Tax') are compared as follows. The aid amount corresponding to each vulnerable-consumer cluster, identified by the Province of residency and the vulnerability level, was subtracted from the cluster's RTEE. Therefore, the indicator was calculated for the two alternative scenarios, considering the reduction in expenditure produced by, respectively, the TSA or TEC application.

Finally, a complementary analysis was carried out as follows. The calculation of the TEC impact was repeated to identify the percentage of RTEE that should be covered by the cheque, depending on the vulnerability level, in order to achieve the energy poverty reduction targets of the SNSEP (25% and 50%). Furthermore, the ideal scenario of eradication of WEP was assessed and the national annual budgets corresponding to each scenario were compared. In the reduction targets analysis, the TEC amount for consumers at risk of social exclusion has not been changed because the paper's first proposal already reduces their share of WEP by 100%.

Table 2 shows an example of the WEP estimation for the province of Madrid in the six analysed scenarios. The consumer clusters whose share of RTEE in income is more than twice the M_t ($2M_t$=5.1% for 2018) are highlighted in blue and counted as winter energy poor.

	Vulnerable consumers								Severe vulnerable consumers								Consumers at risk of social exclusion							
Scenario	**P**	**0 MN**	**0 MN***	**1 MN**	**1 MN***	**2 MN**	**2 MN***	**L**	**P**	**0 MN**	**0 MN***	**1 MN**	**1 MN***	**2 MN**	**2 MN***	**L**	**P**	**0 MN**	**0 MN***	**1 MN**	**1 MN***	**2 MN**	**2 MN***	**L**
Before aid	-	10.1%	7.6%	7.5%	6.0%	6.8%	5.7%	-	16.2%	20.1%	15.1%	14.9%	11.9%	13.7%	11.4%	9.8%	16.2%	20.1%	15.1%	14.9%	11.9%	13.7%	11.4%	9.8%
After TSA	-	9.5%	7.1%	7.0%	5.6%	6.5%	5.4%	-	14.8%	18.2%	13.7%	13.5%	10.8%	12.5%	10.4%	9.1%	14.8%	18.2%	13.7%	13.5%	10.8%	12.5%	10.4%	9.1%
After TEC	-	7.6%	5.7%	5.6%	4.5%	5.4%	4.5%	-	10.3%	12.3%	9.2%	9.0%	7.2%	9.0%	7.5%	6.9%	1.5%	0.5%	0.4%	0.2%	0.2%	1.9%	1.6%	2.4%
25% WEP reduction	-	6.1%	4.6%	4.5%	3.6%	4.5%	3.7%	-	7.7%	8.8%	6.6%	6.4%	5.1%	6.8%	5.7%	5.5%	1.5%	0.5%	0.4%	0.2%	0.2%	1.9%	1.6%	2.4%
50% WEP reduction	-	5.2%	3.9%	3.8%	3.0%	3.9%	3.2%	-	6.0%	6.6%	4.9%	4.8%	3.8%	5.5%	4.6%	4.7%	1.5%	0.5%	0.4%	0.2%	0.2%	1.9%	1.6%	2.4%
WEP eradication	-	3.0%	2.3%	2.2%	1.7%	2.6%	2.2%	-	3.4%	3.1%	2.3%	2.1%	1.7%	3.4%	2.8%	3.4%	1.5%	0.5%	0.4%	0.2%	0.2%	1.9%	1.6%	2.4%

* For the following special circumstances:

- Recognised disability ≥ 33%
- Victim of gender violence
- Degree of dependency, grade II or III
- Single-parent families

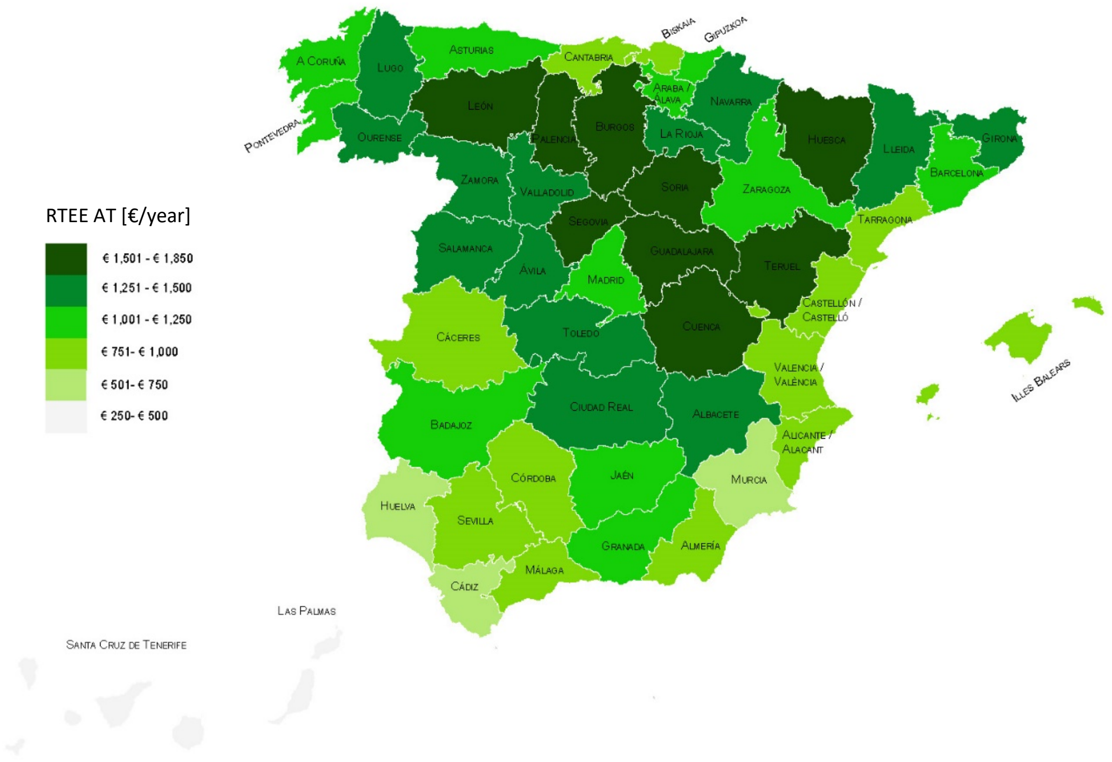
Table 2. Example of the WEP estimation: share of RTEE in income of the consumer clusters in the six analysed scenarios for the province of Madrid. The consumer clusters in WEP are highlighted in blue (P - Minimum Pension; MN - Minor(s); L - Large family).

Table 2 highlights the different impact of the two measures analysed (TSA and TEC) on the reduction of the household share of RTEE in income and, therefore, on WEP. The last three scenarios constitute a complementary analysis on the calculation of the national budget to achieve the SNSEP targets and the ideal eradication of WEP.

4. Results and discussion

Fig. 4 summarizes the results of the two scenarios of RTEE analysis (before and after taxes) for the 'provincial weighted-average households' defined by the segmentation methodology described in Section 3.1. The RTEE values for Ceuta and Melilla, which are two small Spanish provinces in the North African coast (not shown in Fig. 4), are the following ones: €666 and €533 for RTEE AT; €628 and €503 for RTEE BT.

The RTEE varies considerably depending on the province. Considering the scenario BT, the average RTEE in the coldest province (León) is six times higher than the warmest-province's one (Las Palmas). Furthermore, Fig. 4 points out that the difference between the RTEE of the two scenarios is significantly smaller in Canary Islands (Las Palmas and Santa Cruz de Tenerife), Ceuta and Melilla because the VAT is much lower than in the rest of the provinces, where it is 21% for all energy supplies (see Appendix C). That means also that fossil fuel taxes have a lower weight in the energy expenditure than the VAT. The weighted average values of RTEE, respectively after and before taxes, are €1,055 and €812. From this, it can be inferred that the overall taxation is 23% of the average RTEE AT, which confirms the abovementioned conclusion on energy taxation in Spain.



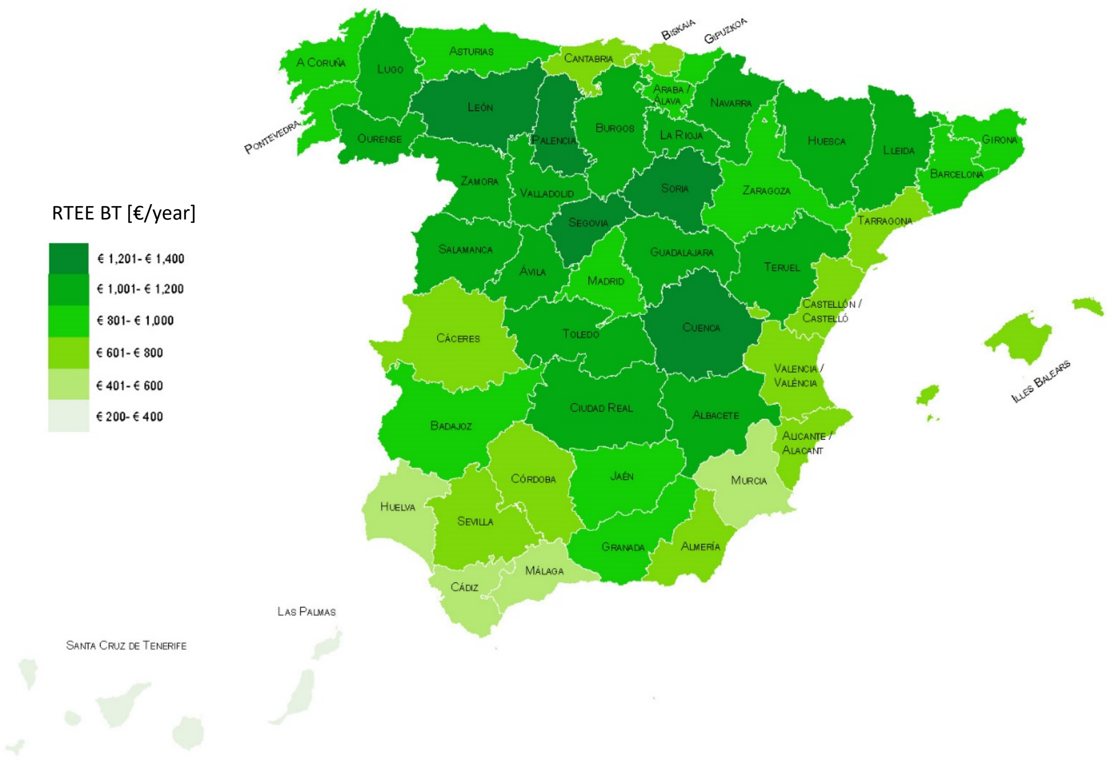


Fig. 4. Provincial results for the two scenarios of the household RTEE analysis [€/year]: RTEE AT - RTEE after tax (above); RTEE BT- RTEE before tax (below)

For reference purposes, the cost to cover 100% of the RTEE for all vulnerable consumers in the two scenarios is, respectively, AT €1.394m and BT €1.070m approx. However, the objective of the TEC policy presented in this paper is not to cover 100% of this cost, but to support (for a short period of time, pending the implementation of structural measures) a percentage of the RTEE that varies according to the consumer's vulnerability level.

Two different values of TEC-annual-budget were obtained by applying Eq. (3) to the two abovementioned RTEE-scenarios (see Appendix D): AT €455m and BT €349m approx. The second scenario is selected for the comparison among the climate zones because it eliminates the distortion introduced by the different taxation applied in some provinces, whereas the first scenario represents the actual paper's proposal.

Fig. 5 compares the values of the proposed TEC in scenario BT with the 2019 TSA (presented in Section 2.3), for each consumer category, in six provinces representative of the six Spanish winter climate zones. In the proposed TEC, the smaller amount corresponding to the mildest climate zone (α) is related to DHW expenditures. Meanwhile, the cheque of the coldest zone is significantly greater than the other zones' one because of the considerable higher heating expenditures. In the case of consumers at risk of social exclusion, the TEC is much higher than the ones of the other two categories. However, this does not result in a significant rise of the TEC-annual-budget because in 2019 this category of consumers was only 0.5% of beneficiary households [59].

Comparing the TEC with the current allowance (Fig. 5), there is a clear evidence that the TSA is covering only a small percentage of the RTEE of Spanish vulnerable households (5.5% on average). Whereas, the proposed energy cheque, if applied, would cover on average 33% of households' theoretical heating-and-DHW expenditures. This is particularly noticeable for the consumers at risk of social exclusion, i.e. the poorest ones, who currently receive the same amount of money than the severely vulnerable ones (whereas, applying the proposed TEC, they would receive 100% of the RTEE). The amount differences pointed out in Fig. 5 are mostly explained by the fact that the TSA-annual-budget in 2019 (€75m, see Section 2.3) was, respectively, 16.5% and 21.5% of the proposed TEC budget in the two scenarios (TEC AT, €455m, and TEC BT, €349m; see Appendix D). This produced a slight increase in the TSA amount with the winter severity. The households living in the coldest zone were clearly the most affected by this fact since they received a cash transfer that was between 7% and 17% of the TEC AT. This meant also that the TSA amount of zone E in 2019 was only three times the one of zone α. So, the subsidy-rise with the winter severity was only half the increase of the RTEE-value.

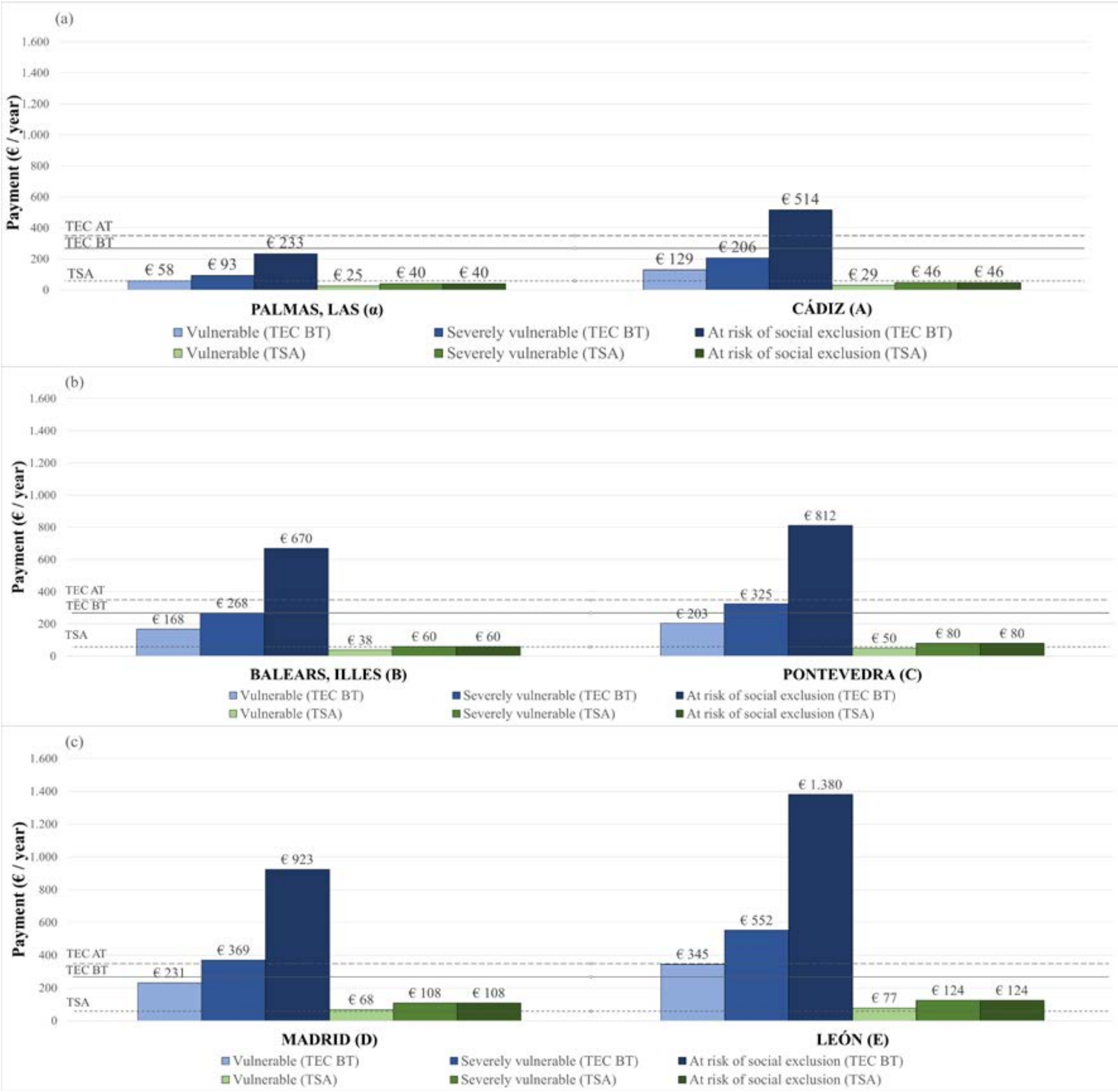


Fig. 5. Comparison between the proposed TEC in Scenario BT and the current TSA (2019), per winter climate zone and consumer category: (a) Warm climate zones, (b) Temperate climate zones, (c) Cold climate zones. The national average payment values are shown as lines in the chart.

The energy cheque proposed in this paper (TEC AT) is, on average, €349 per household. Table 3 shows the comparison among the proposed TEC and the mitigating measures implemented in the UK and France in 2019.

Measure	Energy services	Energy carriers	Average payment [€ / year]
TEC (ES)	Heating and DHW	All	€349
Winter Payments (UK)	Heating	Electricity / Gas (one allowance) and Unspecified (two allowances)	€388
Energy Voucher (FR)	All	All	€200

Table 3. Comparison among the proposed TEC (Spain) and the mitigating measures implemented in the UK and France in 2019

Bearing in mind the differences and similarities of these measures (Table 3), the TEC average payment would be in between the average Energy Voucher in France (€200) and the sum of winter payments assigned to vulnerable households in the UK (€388). However, for a rigorous comparison, the values would have to be adjusted to take into account the differences in socio-demographic characteristics and climate. Furthermore, it should be noticed that the French Energy Voucher was designed to support all domestic energy costs.

Table 4 shows the results of the analysis of, respectively, the TSA's and TEC's impact on the proportion of winter energy poor households in the vulnerable-consumers sample [59], estimated using the $2M_t$ indicator explained in Section 3.2.1 ($2M_t$=5.1% for 2018).

Scenario	Vulnerable consumers	Severe vulnerable consumers	Consumers at risk of social exclusion	Total	WEP variation
Before aid	91%	98%	100%	96%	0%
After TSA	90%	98%	100%	95%	-1%
After TEC	72%	93%	0%	85%	-11%

Table 4. Proportion of winter energy poor households in the 2019 vulnerable-consumers sample before and after the application of the analysed policies.

The implementation of the TSA in 2019 reduced the proportion of energy poor by only 1%. Replacing the current allowance with the energy cheque proposed in this paper would lead to more significant WEP reduction (11%)[13]. Nevertheless, this reduction is still below the SNSEP targets. Thus, Fig. 6 shows the TEC amount (as percentage of RTEE, i.e. the parameter f_v in Eq. (3)) needed to achieve the abovementioned targets and the ideal eradication of WEP. It is important to note that this analysis does not incorporate the possible implementation of other types of energy poverty measures, such as the structural ones, which could reduce the households' RTEE, thus reducing the share of winter energy poor households.

[13] It should be highlighted that this is a theoretical assessment sensitive to the indexes used for the equivalisation of energy expenditures (see Appendix E).

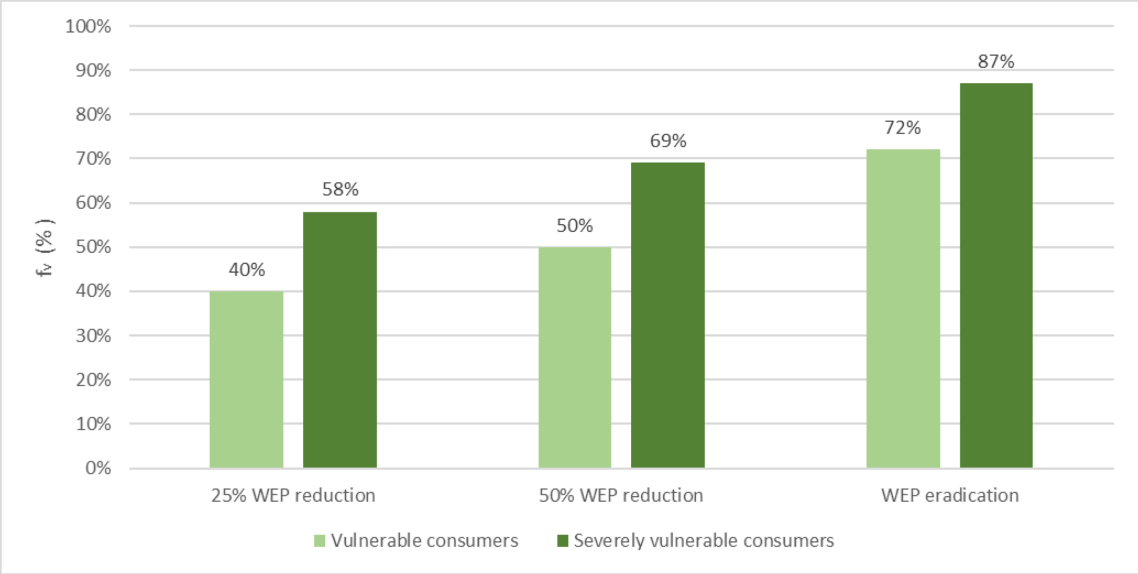


Fig. 6. Values of the parameter fv needed to achieve the SNSEP reduction targets (25% and 50%) and the ideal eradication of winter energy poverty.

The corresponding annual national budgets for these three scenarios are €597m, €724m, and €967m, which are, respectively, eight, ten and thirteen times the 2019 TSA budget.

Briefly, according to the results presented in this paper, the 2019 TSA had a limited impact on WEP. On the other hand, the proposed TEC would improve the ability of vulnerable households to pay their 'winter's energy bills', thus achieving a higher reduction of WEP.

Nevertheless, it should also be noted that allocating a higher amount of the cheque to less efficient housing might seem to be a disincentive for households to make energy-efficiency improvements. However, the TEC is proposed as a short-term measure to alleviate the effects of energy poverty on vulnerable households (who cannot afford to retrofit their houses or pay higher rent to live in more efficient housing). Nonetheless, this energy cheque, with the current residential building stock, is a costly measure, as shown in the complementary analysis on the calculation of the national budget to achieve the SNSEP targets. Therefore, in the medium to long term, it should be combined with a comprehensive building renovation plan, such as the 2020 Spanish Strategy for Energy

Renovation in the Building Sector[14] [63], which will progressively improve the energy efficiency of housing, thus reducing households' energy expenditures. Further work could use the proposed methodology to evaluate the effect of this plan on the RTEE (from the improvement of the energy efficiency class), and its impact on WEP.

Furthermore, this approach might be extended to other European countries, thus promoting an enhancement of the current measures to help vulnerable households to address their energy needs in the short term. This analysis could be carried out by considering the differences in climate classification, building stock and household characteristics, according to the national regulation and statistical data (usually provided by Eurostat and national statistical institutes).

The methodology used to characterize the RTEE of Spanish households is based on the Spanish building regulation, official surveys and the report on building certification, which are periodically updated. This makes it possible to keep the results updated considering the most recent data available. Moreover, the flexibility of the model makes it also a useful tool for policy planning. Eventually, the model could allow households and stakeholders to easily assess theoretical thermal-energy expenditures and the TEC amount assigned. The TEC proposal is especially oriented to cover the energy needs of households who are too poor to afford any heating (zero heating expenditures) or have very low heating consumption, i.e. the ones in hidden energy poverty [45]. Indeed, the TEC is an energy cheque that depends on the required thermal-energy expenditure of each household. This is a novel concept that differs it from the TSA and goes beyond the mechanism of the social tariff for electricity, which is a discount on actual household expenditure. In the TEC proposal, a household that spends too little (or zero) on heating

[14] Published in 2020 within the framework of the EU Member States' long-term renovation strategies.

would receive a cheque to increase its consumption and achieve (or be closer to) an acceptable level of comfort in home. On the other hand, it has already been proven [39] that the discount on actual expenditure of the social tariff for electricity has not improved significantly the comfort condition of Spanish vulnerable households.

In this context, it has to be noted that the current mitigating measures do not reach all those who need it because of their vulnerable situation [39]. For example, there are people in situations of substandard housing or who do not have a VPSC contract (see Section 2.3) who, with the current allocation criteria, cannot access the discounts of the social tariff and, thus, do not receive the TSA. Furthermore, the lack of information is also a problem for some vulnerable households that do not know about the support or do not know how to apply. Indeed, in 2019, 1.3 million households benefitted from the TSA, whereas, for the same year, the Ministry for the Ecological Transition identified between 1.2 and 3.1 million households as energy poor (depending on metric used). Therefore, in economic terms, the annual budget should increase by 238% to extend the proposal of this paper (TEC AT) to the high value in the range of energy poor households (ceteris paribus).

5. Conclusions and policy implications

According to the IDAE report on 2018 Spanish residential demand [25], the final energy consumption for heating and DHW was more than 59% of the total final domestic energy consumption. The calculation of the theoretical thermal-energy expenditures of Spanish households, carried out in this paper, shows that families' heating-and-DHW needs require an average annual cost of €1,055. In this regard, it is striking that the mitigating measures proposed to tackle energy poverty in Spain between 2011 and 2018 have been exclusively focused on electricity consumption. In the same years, other European countries, such as the UK, have been mainly supporting the heating costs of vulnerable households rather than the electrical ones, in accordance with the literature on energy poverty.

The inclusion for the first time in RDL 15/2018 of a 'Thermal Social Allowance' (TSA) marked a change in the Spanish trend. The TSA was designed as a transfer-in-cash for vulnerable consumers to support heating, DHW, and cooking costs. It mainly depends on the climate zone of the household's location, which is not considered in similar policies of other European countries, e.g. the French Energy Voucher and the British winter-payments' scheme. However, the TSA policy would benefit from a change in the calculation method as the one proposed in this work, i.e. the Thermal Energy Cheque (TEC). The TEC scheme is based on a more accurate quantification of domestic thermal energy needs, i.e. the Required Thermal-Energy Expenditure (RTEE) methodology. This model assesses the household theoretical expenditure required to ensure the indoor environment comfort during winter (heating) and to provide an adequate level of domestic hot water (DHW), considering climate zone, dwelling characteristics, and household size (only for DHW). The RTEE analysis has been carried out at the provincial level, starting from the calculation of the annual required demand for heating and DHW for each of the 8,131 Spanish localities.

Thus, this paper presents a proposal for an energy-needs-based Thermal Energy Cheque (TEC) as an enhancement to the TSA. Two different scenarios have been analysed, by using the vulnerable consumers' data of 2019, to consider the possible tax changes that could be implemented in the future. Scenario AT (RTEE after tax) is a no-tax-changes outline representing the implementation of the paper proposal in the current Spanish situation. Scenario BT (RTEE before tax) is an ideal setting where no taxation is applied to vulnerable-households' energy-bills. The budget difference between the two scenarios

(€106m approx.) corresponds to the amount of money related to energy taxation, which might change in case of a new VAT policy for vulnerable consumers or changing in fuel taxation.

The analysis carried out in this paper points out that the 2019 average-TSA-value (€58) was 16.5% of the average TEC in Scenario AT (€349) and covered only 5.5% of the average household's RTEE. In contrast, the proposed TEC would cover, on average, 33% of households' theoretical heating-and-DHW expenditures. Furthermore, this cheque would be comparable to the energy-subsidy amounts assigned to vulnerable households in the UK (€388) and France (€200).

Scenario BT makes it possible to analyse the proposed TEC policy across the Spanish winter climate zones because it eliminates the distortion introduced by the different taxation applied in certain provinces. This analysis points out that the TEC in the coldest climate zone (E) would be six times higher than in the mildest climate zone (α). Furthermore, the difference between the two scenarios' RTEE values is significantly smaller in the Canary Islands, Ceuta and Melilla, because in these provinces, the VAT values are much lower than the rest of the country. This result highlights that fossil fuel taxes have a lower weight in the energy expenditure than the VAT.

According to the results presented in this paper, the 2019 TSA reduced winter energy poverty (WEP) in Spain by only 1%. On the other hand, the proposed TEC would increase the reduction of winter energy poor households up to 11%. Furthermore, this paper presents a complementary analysis on the calculation of the TEC national annual budget to achieve the SNSEP targets and the ideal eradication of WEP. Nevertheless, it is essential to highlight that the analysis presented in this paper does not consider the possible implementation of structural measures, such as housing energy retrofits. Further work could use the proposed methodology to evaluate the effect of these measures on the RTEE (from the improvement of the energy efficiency class), and their impact on WEP.

In summary, the TEC policy proposed, based on the theoretical domestic thermal-energy expenditures, makes it possible to consider the differences in climate, dwelling characteristics, and household size. This is a ground-breaking concept that goes beyond the mechanism of the social tariff for electricity, which is a discount on actual household expenditure. In the TEC case, a household that spends too little (or zero) on heating because of low-income (hidden energy poverty) would receive a cheque to increase its consumption, thus achieving (or getting closer to) an acceptable level of comfort at home. Furthermore, its implementation would improve some of the criteria currently used for the definition of the TSA, which, in 2019, had minimal impact on WEP. However, in the paper case study, it is not possible to estimate the effect of these measures on hidden energy poverty (HEP) because the actual consumption of the sampled households (vulnerable consumers) is not known. Additionally, the 2M methodology used for the WEP assessment is not based on household actual expenditure but on its required energy expenditure, thus including an absolute threshold instead of a relative one. On the other hand, future work might use an absolute threshold, such as the RTEE, to estimate a HEP indicator in Spain by using the Household Budget Survey data. A proxy of this metric was proposed in a study that characterized a sample of vulnerable household assisted by a Spanish NGO [64].

Eventually, the proposed TEC formula might allow policymakers to assess the effect of changes in energy prices and taxation. Nevertheless, future work should reflect that the current mitigating measures do not reach all those who need it because of their vulnerable situation. Indeed, the allocation criteria for the social tariff are in the process of being revised by the Spanish Government to consider both social and regulatory issues.

Moreover, the RTEE model shows some methodological limitations stemming from the simplifying assumptions. The Required Thermal-Energy Demand (heating and DHW) was assessed using a stationary method established in the official regulation. This method does not consider the change of the involved parameters, such as heating installations' operation, i.e. consumption patterns, which might vary because of the personal and changing nature of these needs [65]. However, the influence of basic parameters such as dwelling size and household size on heating and DHW needs was reflected in the calculation of the RTEE. Further work is planned to enhance the equivalisation method and include additional household characteristics in a broader model of energy expenditures that takes into account other domestic energy services, such as cooking and lighting. Moreover, an extensive analysis is still needed to consider the differences in minimum income standards of households living in different areas of the country. Nevertheless, it has to be highlighted that the cost-of-living disaggregation was not included in the proposed policy because the TEC is intended to be a feasible alternative to the TSA that does not entail an administrative burden beyond the competencies of the governmental body that manages it. Furthermore, fuel prices do not vary significantly across the country, so providing an energy cheque based on households' thermal needs can be considered an equitable approach to the problem of energy poverty.

The study that has been carried out so far has not considered the cooling demand, given that in 2018 the final consumption of the space cooling service in Spain was only 1%[15] of the final energy consumption of the residential sector [25]. Nevertheless, it will be addressed in the near future, given the growing importance of air conditioning in summer (as pointed out in [66]), especially in the hot areas of Spain. Moreover, one crucial line

[15] This low percentage is also due to the reduced ownership of cooling systems in Spain (according to the most recent official statistics, only 35.5% of households own air-conditioning units [66]) and the fact that cooling is still considered a luxury.

for future research might be to use the residential-energy-needs model proposed in this paper to assess the impact of both mitigating and structural measures in reducing energy-poor households. Furthermore, the TEC proposal will be extended to other European countries, thus promoting an enhancement of the current measures to consider vulnerable-households' energy needs in the EU.

This work points out the importance of designing effective measures to support vulnerable-households' thermal energy costs. On the one hand, these services account for most of the total final energy use in the EU residential sector. On the other hand, vulnerable households tend to use heating installations sparingly to reduce their energy bills, often living in unhealthy conditions. Therefore, it is necessary to enhance the current allowance policy in the short term because an accurate and immediate implementation of mitigating measures is needed to improve energy-poor households' health and wellbeing. Nevertheless, the proposed TEC per se cannot be the solution to energy poverty in the medium to long term, notably because of its high annual cost and the need to improve the energy efficiency of homes (especially those inhabited by vulnerable households). Instead, it should be complemented by structural measures, such as building energy retrofits. These two kinds of measures implemented together could avoid 'chronifying' the issue, thus helping vulnerable households get out of energy poverty.

Declarations of 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.

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Appendices

Appendix A. Income and consumption thresholds of the Spanish social tariff for electricity

Vulnerability level	Discount	Household category							
		Minimum pension	Without minors		1 minor		2 minors		Large family
Vulnerable	25%	All members are pensioners with minimum pension	€11,279 (1.5xIPREM)	€15,039 (2xIPREM)*	€15,039 (2xIPREM)	€18,799 (2.5xIPREM)*	€18,799 (2.5xIPREM)	€22,559 (3xIPREM)*	Non-compulsory income requirements
Severely vulnerable	40%	€7,520 (1xIPREM)	€5,640 (0.75xIPREM)	€7,520 (1xIPREM)*	€7,520 (1xIPREM)	€9,399 (1.25xIPREM)*	€9,399 (1.25xIPREM)	€11,279 (1.5xIPREM)*	€15,039 (2xIPREM)
At risk of social exclusion	100%	If the beneficiaries fulfil the requirements to be considered a severe vulnerable consumer and, in addition, the social services pay at least half of the amount of the electricity bill, they will not have to pay the bill.							
Annual consumption with discount		1,932 kWh	1,380 kWh		1,932 kWh		2,346 kWh		4,140 kWh

* For the following special circumstances:

- Recognised disability ≥ 33%
- Victim of gender violence
- Degree of dependency, grade II or III
- Single-parent families

Table A1. Income and consumption thresholds of the Spanish social tariff for electricity per vulnerability level and household category. IPREM – Public indicator of Multiple Income (€ 7520/year for 2018 [67], *as well as for 2019)*

Appendix B. Heating and DHW demand per Spanish locality

The heating demand has been calculated using the methodology described in the report carried out by the IDAE [52] and applying the CTE 2019. The values of annual specific reference-demand for heating (SD_h, in $kWh/(m^2\ year)$) were calculated by the IDAE by applying Eq. (A1).

$$SD_h = (a + b \cdot WS) \quad (A1)$$

Where WS is the winter severity index, which is estimated for each winter climate zone from the Heating Degree Days (HDD) and the ratio of the number of sunshine hours to the number of maximum sunshine hours; a and b are the correlation coefficients, which are the result of modelling thirteen types of building geometry [52] and vary according to the dwelling typology (block dwelling or single-family house).

The values of SD_h for each winter climate zone are shown in Table A2 [68].

Winter climate zone	Block dwelling	Single-family house
α	0.0	0.0
A	13.8	23.6
B	20.9	33.5
C	35.2	53.3
D	53.0	78.0
E	71.2	103.3

Table A2. Annual reference-demand for heating [kWh/(m² year)] per each Spanish winter climate zone and dwelling typology ([68]*)*

Based on those SD_h reference values, the values of SRD_h per Spanish locality were calculated using Eq. (A2).

$$SRD_h = (CF \cdot SD_h) \quad (A2)$$

Where CF is a correction factor that depends on the energy efficiency parameter (EEP) of the dwelling and on a dwelling dispersion factor, both defined in [52]. Thus, three energy efficiency categories have been defined by cross-referencing the buildings age data of the CENSUS 2011 [55] with the report on the status of energy certification of buildings of December 2018 [69]. As a result of this cross-correlation, an energy efficiency class was assigned to each aggregated-construction-period as follows. An energy class between F and G (very low energy performance) was assigned to buildings constructed before 1981, i.e. before the application of the first Basic Building Standard NBE-CT 79 [70]. The abovementioned legislation sets out minimum energy efficiency requirements for the building sector, so the average energy class for residences built between 1981 and 2007 reached a level of E, close to D. Finally, an energy class C was assigned to new buildings (2008-2018), i.e. the ones built after the approval of the Basic Document of Saving of energy (DBHE) in 2006 [71] . The 2018 report on the status of energy certification of buildings made it possible to consider also the energy certificates of residences built between 2011 and 2018, although the number and type of houses refer to the stock built before the CENSUS 2011 (which is the last official dataset available on this topic). Tables A3 and A4 show the values of the EEP resulting from the above described cross-correlation.

Winter climate zone	**≤1980**	**1981-2007**	**2008-2018**
A	4.41	2.46	0.86
B	4.01	2.32	0.83
C	3.69	2.21	0.81
D	3.53	2.16	0.80
E	3.45	2.13	0.79

Table A3. Values of EEP per each Spanish winter climate zone and aggregated-construction-period for block dwellings

Winter climate zone	**≤1980**	**1981-2007**	**2008-2018**
A	4.15	2.13	0.80
B	3.97	2.12	0.80
C	3.81	2.14	0.80
D	3.68	2.10	0.79
E	4.03	2.20	0.81

Table A4. Values of EEP per each Spanish winter climate zone and aggregated-construction-period for single-family houses

The energy efficiency parameter for block dwellings increases with the winter climate zone, i.e. residences in cold climates have higher energy performance than the ones in warm zones. This tendency is not so clear for single-family houses.

Subsequently, the annual specific required demand for DHW (SRD_{DHW}, in kWh/(person year)) per Spanish locality was calculated applying Eq. (A3) [53] to the average monthly network-water-temperature (ºC) of the Spanish provincial capitals (CTE 2019). For localities other than the provincial capitals, the network-water-temperature was calculated by subtracting a factor, defined in CTE 2019, which depends on the difference between the altitude of the locality and that of its provincial capital.

$$SRD_{DHW} = \sum_{i=1}^{12} \frac{SD_T \cdot (T - T_i) \cdot 4{,}176 \cdot n_i}{3600} \tag{A3}$$

In Eq. (A3), SD_T is the daily specific hot water consumption (l/(person day)) at a given temperature T = 60 °C, which depends on the dwelling type; T_i is the average monthly network water temperature (°C), which depends on the locality considered; n_i is the number of days of the i-th month.

Tables A5 and A6 show the values of the annual specific required demand for heating (SRD_h) per winter climate zone and aggregated-construction-period.

Winter climate zone	**≤1980**	**1981-2007**	**2008-2018**
A	51.39	29.26	11.08
B	70.97	41.96	16.30
C	110.14	67.45	26.79
D	159.08	99.24	39.87
E	209.17	131.76	53.25

Table A5. Values of the annual specific required demand for heating [kWh/(m² year)] per winter climate zone and aggregated-construction-period for block dwellings

Winter climate zone	≤1980	1981-2007	2008-2018
A	82.89	43.55	17.86
B	105.58	59.21	25.99
C	149.59	90.26	42.67
D	212.26	129.97	62.01
E	276.32	167.96	86.37

Table A6. Values of the annual specific required demand for heating [kWh/(m² year)] per winter climate zone and aggregated-construction-period for single-family houses

Apart from the climate zone, the value of SRD_h is considerably affected by the dwelling's construction-period and typology. The average SRD_h of a block dwelling in a building constructed before 1981 is 4.1 times the one of a new built dwelling (2008-2018). On the other hand, the specific required demand for the DHW production (SRD_{DHW}) is significantly affected by the network water temperature throughout the year.

Appendix C. Prices and taxes of domestic energy carriers

For electric and natural gas heating systems, the energy prices were set out as the regulated market tariffs in 2019: VPSC for electricity [72] and the Tariff of Last Resort for natural gas (weighted average price from [73] and [74]). The IDAE reports and the 2019 legislation were used as reference for the other energy carriers' price: LPG (weighted average price from [75] and [76]), heating gas oil and biomass (both in [77]). The fossil-fuel and electricity taxes and the VAT have been applied to the energy cost according to the Spanish regulation [77,78], considering the different VAT policy in Canary Islands (Las Palmas and Santa Cruz de Tenerife), Ceuta and Melilla. In these provinces, the VAT values applied to energy supplies are lower than 8%, whereas it is 21% in the rest of the country.

Appendix D. Thermal Energy Cheque annual budget

The TEC budget for each province has been estimated applying the results shown in Fig. 4 to Eq. (3). The number of households who benefited from the subsidy in each province, provided by the Ministry for the Ecological Transition and the National Commission on Markets and Competition in response to two different inquiries [59,60] was used to quantify the provincial budgets that would have been required for 2019. Finally, the national TEC budget was estimated summing up all the provincial ones.

Table A7 shows the distribution of the proposed TEC-annual-budget (Scenario AT) among the Spanish provinces, divided depending on the vulnerability level. In 2019, the subsidy's beneficiaries were 7% of the Spanish households but they were not equally spread among all provinces. The greater relative percentages of TSA-beneficiaries were accounted in three regions: Castilla y León, Castilla–La Mancha and Extremadura. The first two ones, i.e. the inland regions bordering the province of Madrid in Fig. 4, are the coldest regions in Spain and the last one is the region with the higher percentage of consumers at risk of social exclusion.

In Scenario AT, 59% of TEC-annual-budget would be assigned to severely vulnerable consumers. This category consists of almost the same number of households as the vulnerable one, but it has a higher cheque assigned (as shown in Fig. 5), which determines a greater annual budget.

Region	Province	Vulnerable consumers (fv = 25%)	Severely vulnerable consumers (fv = 40%)	Consumers at risk of social exclusion (fv = 100%)
ANDALUCÍA	ALMERÍA	€ 1,885,490	€ 2,901,120	€ 0
	CÁDIZ	€ 3,103,657	€ 4,581,067	€ 9,149
	CÓRDOBA	€ 3,414,191	€ 5,131,644	€ 1,850
	GRANADA	€ 4,729,375	€ 7,546,989	€ 1,137
	HUELVA	€ 1,402,168	€ 1,978,118	€ 0
	JAÉN	€ 4,566,330	€ 7,379,520	€ 0
	MÁLAGA	€ 3,780,110	€ 6,120,121	€ 155,027
	SEVILLA	€ 6,784,343	€ 9,195,054	€ 5,905
ARAGÓN	HUESCA	€ 1,124,411	€ 1,678,694	€ 0
	TERUEL	€ 803,584	€ 1,433,823	€ 1,569
	ZARAGOZA	€ 3,492,031	€ 6,195,654	€ 1,103
ASTURIAS, PRINCIPADO DE	ASTURIAS	€ 3,614,776	€ 8,235,491	€ 8,564
BALEARS, ILLES	BALEARS, ILLES	€ 2,196,435	€ 2,405,437	€ 0
CANARIAS	PALMAS, LAS	€ 599,498	€ 901,642	€ 0
	SANTA CRUZ DE TENERIFE	€ 875,089	€ 1,306,996	€ 0
CANTABRIA	CANTABRIA	€ 1,476,093	€ 2,511,231	€ 0
CASTILLA Y LEÓN	ÁVILA	€ 1,553,536	€ 2,800,799	€ 0
	BURGOS	€ 2,373,385	€ 3,858,388	€ 0
	LEÓN	€ 3,269,558	€ 5,851,619	€ 0
	PALENCIA	€ 1,317,492	€ 2,111,927	€ 0
	SALAMANCA	€ 3,133,370	€ 5,140,541	€ 0
	SEGOVIA	€ 964,419	€ 1,624,832	€ 0
	SORIA	€ 639,880	€ 1,159,426	€ 0
	VALLADOLID	€ 3,140,763	€ 4,966,607	€ 0
	ZAMORA	€ 1,708,449	€ 3,030,704	€ 0
CASTILLA-LA MANCHA	ALBACETE	€ 3,593,881	€ 6,185,409	€ 0
	CIUDAD REAL	€ 4,045,005	€ 6,797,360	€ 0
	CUENCA	€ 2,577,308	€ 4,349,898	€ 0
	GUADALAJARA	€ 1,321,097	€ 1,851,734	€ 1,516
	TOLEDO	€ 4,943,045	€ 8,058,572	€ 0
CATALUÑA	BARCELONA	€ 13,939,201	€ 17,670,805	€ 68,913
	GIRONA	€ 1,866,602	€ 2,479,070	€ 7,752
	LLEIDA	€ 1,363,877	€ 1,975,628	€ 8,778
	TARRAGONA	€ 1,891,618	€ 2,895,783	€ 2,555
COMUNITAT VALENCIANA	ALICANTE/ALACANT	€ 6,245,388	€ 11,004,468	€ 50,466
	CASTELLÓN/CASTELLÓ	€ 1,766,085	€ 2,943,050	€ 0
	VALENCIA/VALÈNCIA	€ 9,368,735	€ 16,058,289	€ 15,752
EXTREMADURA	BADAJOZ	€ 5,922,808	€ 9,021,039	€ 2,217,456
	CÁCERES	€ 2,682,013	€ 4,292,338	€ 727,499
GALICIA	CORUÑA, A	€ 5,118,233	€ 7,849,609	€ 1,461,103
	LUGO	€ 1,708,642	€ 2,820,135	€ 598,270
	OURENSE	€ 2,129,735	€ 3,723,586	€ 516,771
	PONTEVEDRA	€ 3,587,011	€ 5,672,807	€ 1,332,510
MADRID, COMUNIDAD DE	MADRID	€ 23,996,373	€ 29,958,773	€ 12,186
MURCIA, REGIÓN DE	MURCIA	€ 5,301,986	€ 7,296,513	€ 11,729
NAVARRA, COMUNIDAD FORAL DE	NAVARRA	€ 4,308,318	€ 3,178,358	€ 0
PAÍS VASCO	ARABA/ÁLAVA	€ 1,338,389	€ 1,616,417	€ 0
	BIZKAIA	€ 3,418,282	€ 5,176,418	€ 0
	GIPUZKOA	€ 2,685,352	€ 2,263,287	€ 1,123
RIOJA, LA	RIOJA, LA	€ 1,667,601	€ 3,035,181	€ 2,691
CEUTA	MELILLA	€ 12,130	€ 4,266	€ 0
MELILLA	CEUTA	€ 131,449	€ 197,257	€ 0
TOTAL		€ 178,878,597	€ 268,423,493	€ 7,221,374

Table A7. Distribution of the proposed TEC-annual-budget (Scenario AT) among the Spanish provinces (grouped into regions) per consumer category

Appendix E. Equivalisation indexes for heating and DHW expenditures

The indexes to equivalise the RTEE of the consumer clusters shown in Table A1 have been set by following Moore's approach ([3,62]), adjusted to the case study of this work. Firstly, the average household size of each vulnerable consumers' cluster was estimated according to the Spanish 2018 Household Budget Survey, starting from assumptions on the number of adults and minors composing the household. Table A8 shows the values assigned to each cluster.

	Minimum pension	**Without minors**	**1 minor**	**2 minors**	**Large family**
No. of adults	1.6	1.9	2	2	3.6
No. of minors	0	0	1	2	1.8
Household size	1.6	1.9	3	4	5.4

Table A8. Average household size assigned to each vulnerable consumers' cluster

Moreover, the average dwelling size of each cluster was also set according to the Spanish 2018 Household Budget Survey. The reference values are shown in Table A9.

	Minimum pension	**Without minors**	**1 minor**	**2 minors**	**Large family**
Dwelling size [m^2]	101	102	97	106	104

Table A9. Average dwelling size assigned to each vulnerable consumers' cluster

Finally, Table A~~8~~10 shows the indexes comparing heating and DHW required expenditures by consumer cluster. These values were set by applying Moore's methodology to the Spanish case, i.e. taking into account the household characteristics shown in Tables A8 and A9.

	Minimum pension	**Without minors**	**1 minor**	**2 minors**	**Large family**
Heating	1.00	0.94	0.90	1.03	1.17
DHW	1.00	0.86	1.13	1.30	1.56

Table A10. Equivalisation indexes for heating and DHW expenditures (own elaboration following [3,62])

The unit value index was assigned to the ‘national average household’ (2.5 persons living in a dwelling of 103 m^2). The heating indexes are ultimately set according to the assumptions on the dwelling size of the different household clusters (Table A9). For example, the households with one minor have a smaller index value because they have an average dwelling size lower than the rest of the clusters. On the other hand, the DHW indexes mainly depend on the average household size assumed (Table A8). Moreover, the heating and DHW indexes for the minimum pension cluster are calculated considering an increase in energy needs due to age. The same assumption partially explains the higher values of the indexes for large families than those of households with two minors, i.e. there is a higher presence of aged people in large families than in two-minor ones.