Evaluation of tariff structural changes in Spanish households affected by energy poverty

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Abstract. A new structure for regulated tariffs affecting consumers with contracted power up to 15 kW was introduced by the Spanish government in June 2021. According to the National Commission for Markets and Competition the new tariff would impact residential consumers differently, depending on previous contracting conditions. In particular, households under old Time-of-Use tariffs are expected to face a significant increase in their electricity bill, which might be exacerbated by the rising generation costs observed in the Spanish market throughout 2021. This situation becomes more relevant for consumers affected by energy poverty, especially when considering that this group needs to be in a regulated tariff to access social benefits. A set of energy poverty affected households are evaluated during a monitoring campaign carried out in Barcelona's pilot as part of EmpowerMed H2020 project, whose objective is to tackle energy poverty and help improving people's health in the coastal areas of Mediterranean countries, with a particular focus on women. Hourly consumption data is downloaded from the customers' smart-meters, which are accessed through their personal account in the distributor's website. Using this data, the article presents an evaluation of the potential impact that the new tariff structure might have on energy poverty affected households, considering different price scenarios that reflect the observed rising generation costs and the price mitigation measures enacted by the government in an attempt to reduce its impact on domestic consumers.

Keywords. Energy Poverty, Domestic Consumers, Electricity Tariffs, Energy Regulation.
DOI: https://doi.org/10.34641/clima.2022.185

1. Introduction

Although not included as such in the declaration of human rights by the United Nations, the energy use is inherent in almost any human activity and, thus, essential for life [1]. In fact, access to energy, as a human right, has historically been justified as such for being implicit in other effective human rights (i.e. sustainable development right or the right for non-discrimination) [2]. Moreover, since 2015, the 7th sustainable development goal targets to "ensure access to affordable, reliable, sustainable and modern energy" [3], which goes even further than just access to energy.

Nonetheless, this target seems hard to accomplish since, even in Europe more than 15% of the population could be characterized as affected by "fuel poverty" [4]. This situation gets even worse when considering the concept of "energy poverty", which has a wider overview rather than just affordability [5]. This study adopts the concept of "energy poverty" defined by Bouzarovski as "the situation in which a household lacks a socially and materially necessitated level of energy services in the home" [6], which is also used in the EmpowerMed H2020 project that englobes this analysis.

EmpowerMed project aims to mitigate the effect of Energy Poverty (EP) by empowering women (principally) to fight against it [7]. The project has six pilot sites in different regions of the Mediterranean coast where household face difficulties to reach good thermal comfort conditions both in summer and winter. Several approaches are used to this purpose, such as household visit, collective assemblies, do-it-yourself (DIY) capacity activities or workshops. This analysis focusses on the results obtained from the DIY activities carried out in the Barcelona pilot from September 2020 to June 2021, which involved the study of the electricity consumption of a group of EP-affected households through smart meter monitoring as well as bill optimization analysis [8].

This monitoring campaign showed average potential savings per EP-affected household of 42,0 €/year by optimizing their contract conditions. The choice minimizing participants' costs was a regulated contract – known as PVPC for its Spanish acronym – plus the 2.0DHA tariff, a Time of Use (TOU) option with two pricing periods (peak and valley). Two other tariff structures from the PVPC scheme were also available during the campaign, 2.0A – a flat rate tariff - and 2.0DHS, which was optimized for night EV charging. Customers were also advised to lower their contracted power when their maximum demanded power was significantly below the current contracted value [8].

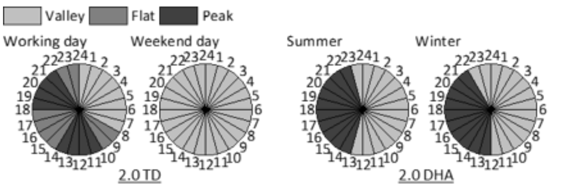

Fig. 1 – Pricing periods considered in tariffs 2.0DHA (abrogated) and 2.0TD (current).

However, a regulatory change introduced in 1st June 2021 put the achieved savings in question as all customers under PVPC contracts were assigned to the 2.0TD tariff, now the only available option under the regulated scheme. This tariff is defined by three pricing periods (valley, flat and peak) as seen in Fig. 1. Weekends and holidays are considered valley, but during workdays, valley hours (late night) are substantially reduced in comparison to the 2.0DHA scheme. Now, hours previously classified as valley are considered flat, which is more expensive. 2.0TD also has differentiated contracted powers for valley and flat-peak times [9]. According to the National Commission for Markets and Competition (CNMC), the new tariff would likely imply larger costs for households previously using the 2.0DHA tariff [10].

In addition, the persistent increase in electricity generation costs has added more concerns, particularly to vulnerable customers. In response, the Spanish government enacted a series of Price Mitigation Measures (PMM) to soften its impact on households' electricity bills. The first set was released in 24th June 2021, being the most relevant for vulnerable customers the transitory reduction of the Value Added Tax (VAT) from 21% to 10% [11]. Other actions were implemented to lower generation costs themselves, but the upward trend was not reversed, which translated into higher active energy prices for PVPC users (Fig. 2).

A second set of PMM was released in 14th September 2021[12]. Among others, it included the reduction of the special tax on electricity from 5,11% to 0,5% and lower access charges imposed to the power-based and active energy components of the 2.0TD tariff. These are responsible for the pattern shift observed in Fig. 2 after this date. In 26th October 2021 [13], the Spanish government released a third set that included larger discounts to beneficiaries of the Social Bonus (SB), a social aid scheme that reduces vulnerable customers' electricity bills up to a certain extent [14]. As happened in June, active energy costs continue rising despite other control actions taken.

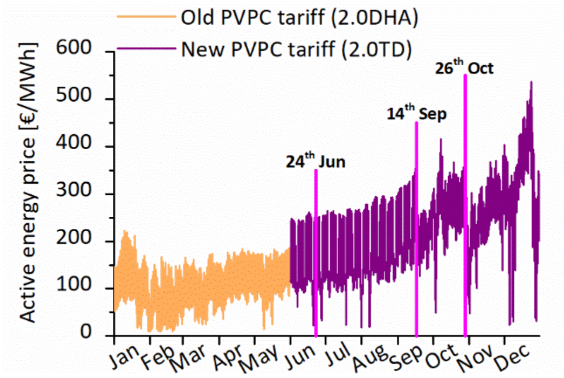

Fig. 2 – Active energy prices registered for the old and new PVPC tariffs during 2021. Pink vertical lines mark the dates on which PMM were applied.

Considering the observed market and regulatory conditions, this article analyses the effect of changing tariff structures under a drastic rise in generation costs to differentiate the impact that each factor has on vulnerable customers. As well, it evaluates the increase or decrease risk to worsening their current EP levels, and the potential role of implemented PMM in softening the negative impact of rising prices on vulnerable Spanish households.

2. Research methods

2.1 Data collection

The EP-affected households included in this study correspond to twelve participants from the EmpowerMed's monitoring campaign carried out in Barcelona from September 2020 to June 2021. Hourly electricity consumption is recovered from the smart-meters installed by the distributor company through a web service. Socioeconomic and energy usage data is gathered using a Google Forms survey. All sampled households attended the collective assemblies organized by the Alliance Against Energy Poverty and had or are in the process of obtaining the Report on Social Exclusion Risk (IRER for its Catalan acronym) issued by social services to officially recognize their vulnerability status [8].

Active energy prices are obtained from the ESIOS platform, operated by the Spanish Transmission System Operator, *Red Eléctrica Española* [15]. The data for the selected pricing periods is downloaded through the platform's Advanced Programming Interface (API) service and cleaned and transformed using a Python script.

2.2 Energy costs calculation

Tariff impact analysis is conducted over two representative weeks for summer (July 6th to 12th 2020) and winter (January 4th to 10th 2021). Data availability from volunteers as well as cooling and heating needs – main drivers for residential electricity demand – are considered in the weeks' selection. During the past 20 years in Barcelona, July has been one of the months with higher reported Cooling Degree Days (CDD), and January with higher Heating Degree Days (HDD) [16]. In particular, the selected summer and winter weeks presented 10 CDD and 71 HDD [17], respectively, which are close to historical average values for both months.

To analyse the impact of price and regulatory changes, nine scenarios are defined as summarized in Tab. 1. Scenarios OT2, NT4 and NT4_NM are evaluated over the winter consumption week, and the rest over the summer week. In all scenarios except NT2_NM, NT3_NM and NT4_NM, all price components and PMM are included based on the actual market and regulatory conditions observed.

Tab. 1 – Characteristics of defined price scenarios.

Scenario	Tariff	Season	PMM
OT1	2.0 DHA	Summer	
OT2	2.0 DHA	Winter	
NT1	2.0 TD	Summer	
NT2	2.0 TD	Summer	✓
NT2_NM	2.0 TD	Summer	
NT3	2.0 TD	Summer	✓
NT3_NM	2.0 TD	Summer	
NT4	2.0 TD	Winter	✓
NT4_NM	2.0TD	Winter	

a. PMM: lower charges on active energy or power-based components, reduced taxes, and larger SB discounts.

The total electricity expenses are calculated considering all the components in the electricity bill, using the methodology set by the government for PVPC tariffs under the old [8] and new schemes [9]. The generation costs used to calculate the active energy component in each scenario correspond to the periods shown in Tab. 2. These are selected considering a Monday to Sunday sequence matching the consumption weeks. The charges imposed over the active energy component are those in force during each considered period, except for NT3_NM and NT4_NM where the regular charges used before the PMM of 14th September 2021 are applied.

The contracted power considered for 2.0DHA scenarios is the Optimal Contracted Power (OCP) established during the DIY campaign and based on the peak power registered by the household during the monitored period. For the new tariff structure that has two different contracted powers, the same value is applied. This was the default option given to customers after the implementation of the tariff 2.0TD; those wanting differentiated values were required to specifically request them [9].

Tab. 2 – Dates considered for the generation costs inputted in each scenario.

Scenarios	Timespan
OT1	24-30 May 2021
OT2	14-20 December 2020
NT1	07-13 June 2021
NT2, NT2_NM	02-08 August 2021
NT3, NT3_NM	20-26 September 2021
NT4, NT4_NM	13-19 December 2021

In scenarios OT1 and OT2, contracted power is charged at 38,04 €/kW-year. For scenarios NT1, NT2, NT2_NM, NT3_NM and NT4_NM a charge of 30,67 €/kW-year is considered for peak-flat periods and 1,42 €/kW-year for valley. In scenarios NT3 and NT4 the reduced charges are applied (23,75 €/kW-year for peak-flat, and 0,98 €/kW-year for valley). The applicable taxes are those in force during the considered timelines, except for scenarios NT2_NM, NT3_NM and NT4_NM where the regular electricity tax (5,11%) and VAT (21%) are applied.

To evaluate the role of the SB as a shielding tool for vulnerable customers, the electricity cost for all scenarios is calculated with and without considering the use of the SB. For this, evaluated households are classified as Vulnerable Customer (VC) or Extremely Vulnerable Customer (EVC) based on their socioeconomic data and the rules defined in [14]. For all scenarios except NT4 a discount of 25% is applicable upon VC's electricity bills and 40% in EVC case. In NT4, 40% and 60% discounts are applicable for VC and EVC as stated in the PMM of 26th October.

2.3 Evaluation metrics

In addition to the cost increase per kilowatt-hour consumed and power contracted in each EP-affected household, the obtained Energy Poverty Ratio (EPR) is selected as a comparison metric. This indicator has been used by the European Energy Poverty Observatory and the Spanish National Strategy against Energy Poverty (2019-2024) as reported by [18] and [19]. The EPR assumes that families with a relationship between energy expenditure and income greater than the national average (2M) – set as 10% by [18] and [19] – are affected by EP. As data about other energy expenses was not available, a modification of the EPR is used in this analysis considering only the electricity expenses incurred by the household (EPR_{elect}). As shown in equation [1], this is calculated on a weekly basis.

$$EPR_{elect} = \frac{Weekly\ electricity\ expense}{Weekly\ household\ income} * 100\ [1]$$

The EPR threshold, 2M, is maintained for comparison purposes, but only as an indication of the household increase or decrease risk to suffer EP under the pricing scenarios defined. No final conclusions regarding the households' EP status is intended as there is not enough information to assess it in this study from the broader definition considered in the EmpowerMed project.

3. Results

The main characteristics of the twelve EP-affected households are shown in Tab. 3. The average number of habitants are 2.25 persons per household and the mean monthly household income is 957.60 €/month. Five households are classified as EVC, four as VC, and H2, H3 and H5 are unclassified. Due to lack of income information, H2 and H3 will not be included in the calculations of the electricity bill after the SB discount and the corresponding EPR_{elect}. H5 will be included but no SB discount will be applied over its electricity expenses as its monthly income is above the threshold established in the SB rules.

Tab. 3 – Main characteristics of analysed households.

Key	Hab.	Income [€/month]	OCP [kW]	SB Category
H1	1	1.150	2,40	VC
H2	8	N.D.	3,00	-
H3	1	N.D.	3,45	-
H4	1	430	2,45	EVC
H5	4	2.500	4,60	-
H6	3	1.500	3,50	VC
H7	1	664	2,30	VC
H8	2	1.000	3,30	EVC
H9	2	500	3,45	EVC
H10	1	576	2,42	EVC
H11	2	652	3,45	EVC
H12	1	604	2,20	VC

Households' daily consumption is analysed for the summer and winter weeks in Fig. 3. The consumption of the EP-affected group tends to be stable throughout the summer, with the group's mean consumption per day fluctuating between 6,34 kWh (Sunday) and 7,98 kWh (Monday). The top outliers' values observed during this season, correspond to H7, which presents a mean daily consumption of 19,66 kWh during this week. Notably, households H2, H5 and H10 report mean daily consumptions below 4,0 kWh and H12 below 2 kWh, which might be explained by the restrictive measures used by some EP-affected users to keep their costs down [8].

During the winter week, the group's mean daily consumption is higher than in summer, fluctuating between 7,42 kWh (Friday) and 11,99 kWh (Monday). There is also higher variability among the group members' daily consumptions, especially Monday and Sunday. During the winter week, H6 and H3 report the highest average daily consumption – 26,97 kWh and 20,94 kWh, respectively – and account for the top outlier values reported in this season. Both of these households, in addition to H8, reported to have electrical heating at home. On the other side, households H4 and H7 registered the lowest mean daily consumptions (< 2,0 kWh).

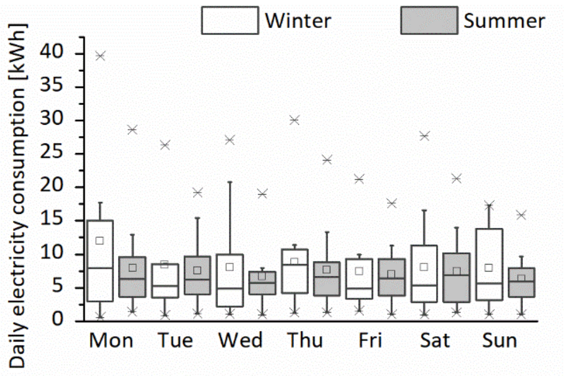

Fig. 3 – Households' mean electricity consumption per weekday (n = 12). Box plot parameters: mean by square; median by horizontal line; 25–75% per-centile by box; 10% and 90% by whiskers; 1% and 99% percentile by cross; minimum and maxi-mum by dash.

In Fig. 4, household's consumption per pricing period is also plotted for the Old Tariff (OT) and New Tariff (NT) scenarios. As observed, most households tend to have lower valley consumptions when considering the new tariff structure, which is expected as valley hours under 2.0TD cover late night and early morning periods when most people are asleep. During flat and peak hours, few households – such as H6 that has high consumption during the flat afternoon period – show differentiated consumptions. For most households, consumption remains stable across flat and peak hours, having a similar distribution between both pricing periods.

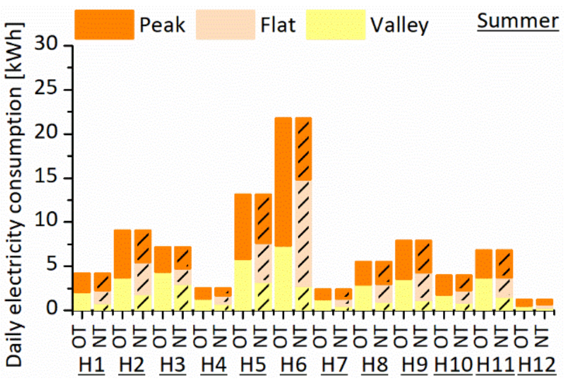

Fig. 4 – Households' mean electricity consumption per hour during the summer week (n = 12). The highlighted pricing periods correspond to tariff 2.0TD.

As explained before, summer peak hours under tariff 2.0DHA were those between 13:00 and 23:00 hours, and the rest were considered valley (Fig. 1). This distribution benefitted most of the households during the target week, as most would take advantage of having longer valley hours, particularly as their consumption tends to rise after 8:00, now considered flat period. H6 is the most benefitted by the new tariff usage as its consumption during flat hours would have been charged with peak prices under 2.0DHA. Having all weekend hours marked as valley instead of two differentiate periods has a soft impact on the sampled households as just three pf them consume considerably more electricity (>10%) in weekends than in workdays during the summer.

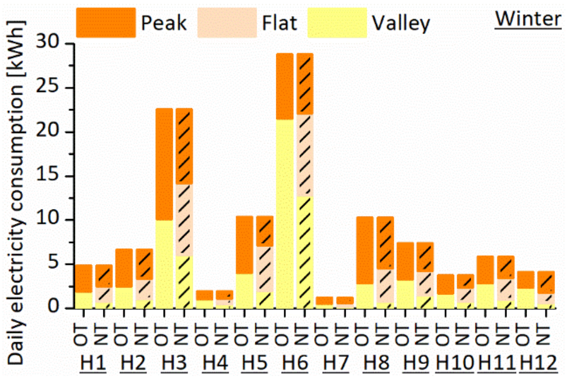

Fig. 5 – Households' mean electricity consumption per hour during the winter week (n = 12). The highlighted pricing periods correspond to tariff 2.0TD.

In winter (Fig. 5), households tend to present larger consumptions and more fluctuating curves, although the lowest consumptions in tariff 2.0TD are also concentrated on the valley hours, except for H6 and H3 that have consumption peaks during the night. It is noticeable that H6's consumption curve changes its peak from a flat period in summer to valley hours in winter, while H5's peak moves from peak to flat hours. H3 and H8 present more pronounced peaks than in summer, which is explained by the use of electrical heating. The rest of households tend to maintain a stable consumption behaviour throughout the day as observed in summer.

Under the old tariff, peak winter hours were those between 12:00 and 22:00 hours. As in summer, such distribution benefitted most of the households, particularly those with no particular peak consumptions during the day.

3.1 Active energy trends during set scenarios

As shown in Fig. 2, active energy prices have been rising consistently in the past following months. This is why the scenarios based on most recent dates tend to have more expensive energy prices than the older ones (Fig. 6 and Fig. 7). The main exception is the scenario OT2 whose prices are higher than those of OT1 even though the latter is more recent. This is due to seasonality effects as, in general terms, winter prices tend to be more expensive than in summer.

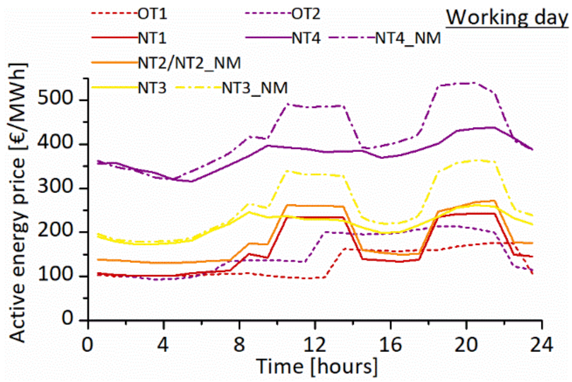

Fig. 6 – Mean active energy price per hour registered in each scenario during workdays.

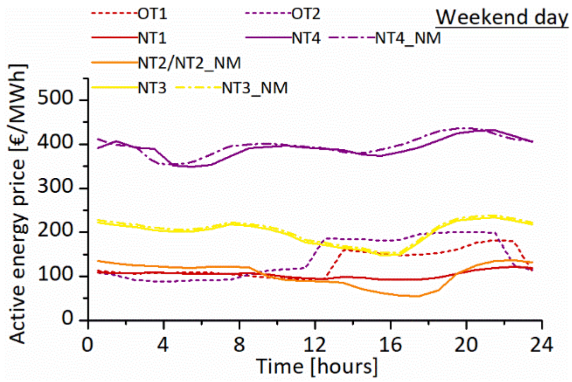

Fig. 7– Mean active energy price per hour registered in each scenario during weekend days.

The effects of the new tariff structure can be clearly identified when comparing the curves of scenarios NT1 and NT2 against those of OT1 and OT2. During working days, the new peak price periods are easily identifiable in NT1 and NT2, having two pricing plateaus instead of one as in the old tariff scenarios (Fig. 6). On the other hand, the curves of NT1 and NT2 are much flatter in the weekends, whereas OT1 and OT2 maintained the observed pricing plateau from Monday to Friday (Fig. 7).

These, however, are dissipated when the reduced charges introduced by the Spanish government in the PMM set of 14th September are considered as observed in the resulting curves for NT3 and NT4 scenarios. These have a stronger impact over workday prices (Fig. 6), as the plateaus observed in NT1 and NT2 flattened, resulting in a similar behaviour to that of the weekends, when only the valley pricing period is considered.

Although the charges applied under the reduced scheme are still differentiated per period, the applied 96% reduction [13] make them less significant in the final active energy price (Fig. 8). In the scenarios in which no reduced charges are considered (NT3_NM, NT4_NM), the peak pricing periods are again distinguishable for workdays. This is not the case of the weekends when considering reduced charges has a minimum impact as they are already quite low for valley hours under normal circumstances.

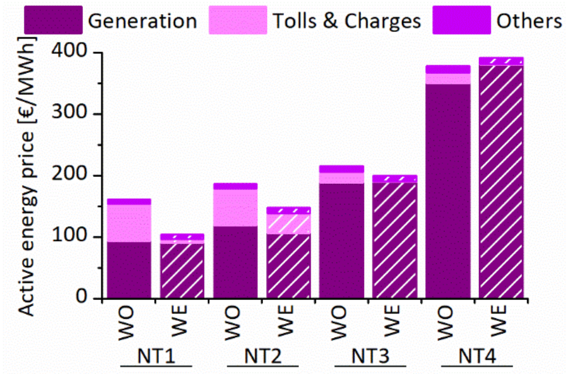

Fig. 8– Mean active energy price per hour registered in each scenario during weekend days.

3.2 Impact on households' electricity expenses

The percentage variation in households' weekly electricity expenses in regards to the old tariff scheme is shown in Fig. 9 (summer scenarios are compared against OT1 and winter scenarios against OT2). For all, except NT4, observed percentage variations remain the same regardless of the SB consideration as the same discounts are applied to all, maintaining an equal relation. The only difference regarding the SB lies on scenario NT4 as larger discounts are used in comparison to the old tariff alternative (OT2) due to the PMM undertaken in 26th October 2021. For that reason, the only distinction between the effect of the SB has been analysed in NT4 (NT4_nSB and NT4_SB, without and with SB).

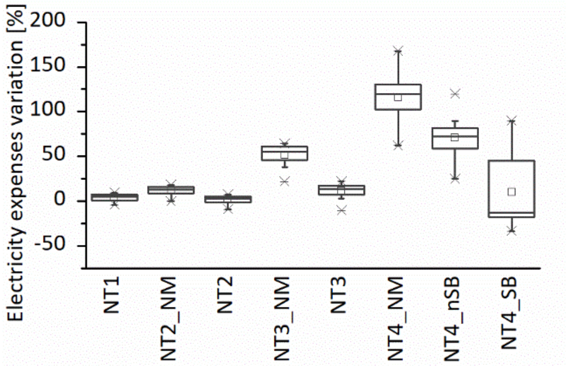

Fig. 9 – Weekly electricity expenses variation from the NT scenarios in comparison to the OT scenarios. Box plot parameters: mean by square; median by horizontal line; 25–75% per-centile by box; 10% and 90% by whiskers; 1% and 99% percentile by cross; minimum and maxi-mum by dash.

As can be observed in the results shown for scenario NT1, the shift to the new tariff scheme does not immediately translate into higher electricity expenses for all households, which together experienced an average increase of 4% under NT1 price conditions. For instance, H4 and H12 show 1% and 4% reductions in their electricity costs. For H12, this is due to its overall low consumption (1.15 kWh/day), which makes more relevant the decrease in contracted power costs introduced in 2.0TD. For H4 – with daily consumption of 7,38 kWh – the results might be explained by the low share of energy it consumes during 2.0TD peak hours: 29%, the lowest in the group.

In scenarios considering more recent dates and no PMM (NT2_NM, NT3_NM and NT4_NM), all households' expenses increase when compared to the old tariff alternatives, particularly in winter scenario NT4_NM in which the mean variation in regard to OT2 is 101%. H4 and H7 present the lowest increases in this scenario; 74% and 52%, respectively. This is explained by the extremely low consumptions (< 2 kWh/day) that both households presented during the representative winter week.

When considering the PMM in scenarios NT2, NT3 and NT4_nSB, households experience still increases in their electricity bills but in a lower degree. In scenario NT2, the lower VAT considered even reduces the final electricity bills of H4, H7 and H12 below OT1 levels; and for all of the users, it reduces the cost in comparison to NT1 levels even though active energy prices were lower in that scenario.

Finally, when considering the larger SB discount in scenario NT4_SB, together with the fiscal reductions imposed, the impact of higher generation costs on sampled households' economy is mitigated. For all households, except H5 and H6, the calculated electricity expenses are lower than for OT2. In the case of H5 because it is not eligible for the SB discount, whereas H6 costs increase are due to their consumption patterns. Specifically, the latter has significant consumptions during the morning that were charged at valley prices during 2.0DHA and now are priced as flat or peak under 2.0TD.

3.3 Observed variations on EPR_{elect}

The households' income and the electricity expenses corresponding to each scenario are used to calculate the EPR_{elect} as explained in the Methodology. During summer, the results obtained indicate that three (H6, H9, H11) out of the ten households surpass the 2M threshold for one or more of the new tariff pricing scenarios without considering the SB (Fig. 10). When applying the SB, H11 manages to move below the threshold, but H6 and H9 still have EPR_{elect} values above 10% for the NT3_NM scenario. Nonetheless, applying the SB plus the PMM manages to keep all households below the 10% threshold during the summer week even during the highest price period considered in this season (NT3).

In winter, the season's higher prices place seven households above the 2M line for at least one scenario when the SB is not considered. If the SB is applied (Fig. 10), three households – H6, H9 and H11 – sill maintain EPR_{elect} values superior to 10%. When considering the government-led PMM (NT4) in addition to the SB discount, EPR_{elect} values lower considerably below the 2M line, and in seven households are even lower than those calculated for OT2. These results highlight the importance of the PMM stablished by the Spanish government in shielding vulnerable customers from price increases.

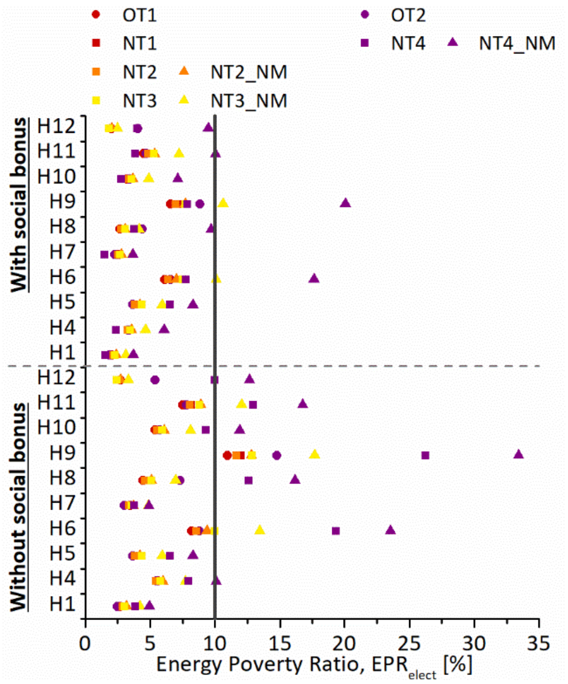

Fig. 10 – EPR_{elect} for analysed households with and without considering the SB (n=10).

4. Conclusions

The implementation of a new tariff structure with three differentiated pricing periods (2.0TD) in June 2021 was expected to impact the electricity expenses of Spanish customers under the regulated scheme, also known as PVPC. This was particularly worrisome in the case of vulnerable customers affected by EP at some level; not only because their economic wellbeing is more sensitive to price increases, but because having a contract under the PVPC tariff is a requirement to obtain the SB, a social scheme that applies a discount over the electricity bill based on the households' vulnerability levels, limiting these users' contracting options.

In addition, the rising generation costs experienced during the past few months that cause the active energy price to spike above historical levels, increased the risk of vulnerable customers with PVPC contracts to worsening its already difficult situation. To protect customers, the Spanish government set in place a number of PMM released in 24th June, 14th September and 26th October of 2021 and still in place by 2022.

The analysis conducted over twelve vulnerable households that participated in the EmpowerMed's monitoring campaign show that the solely consideration of the new tariff scheme might have impacted customers' bill differently depending on their consumption levels and habits, not necessarily resulting in larger expenses. For instance, in the evaluated group, some users actually experienced a reduction in their electricity costs considering the scenario with active energy prices from a few days after the implementation of tariff 2.0 TD (NT1).

Nonetheless, as generation prices increase, all evaluated households end up facing higher electricity expenses when no PMM are taken into account, skyrocketing during the scenario with prices from December 2021 (NT4_NM). This put vulnerable households on risk of worsening their EP status, especially during the winter as active energy prices are the highest of all periods considered.

Without applying any measures or SB, three of the evaluated households have an EPR_{elect} in summer above 10% – the 2M value used as threshold for EP when considering all energy-related expenses – for at least one scenario. In winter, seven households are found in this situation.

During summer, the solely consideration of the SB – without any control measure (NT2_NM, NT3_NM) – seems enough to protect vulnerable customers from a greater risk of worsening their EP situation, as only one household had an EPR_{elect} slightly over the 2M line. But in winter, without considering the PMM, two households report EPR_{elect} above 17% and three more got values close to 10%, which puts them in a higher risk of worsening their EP levels even by applying the SB discount on eligible customers' bills.

Nonetheless, when using the SB in combination with the PMM, all households have an EPR_{elect} below 10% in both seasons This indicates that the introduction of the PMM proposed by the Spanish government seems to serve their purpose, particularly when vulnerable households can access the SB discount.

Up to now, the PMM are considered transitory as a response to unprecedented generation costs. Nonetheless, if the upward trend observed during 2021 continues in 2022, its elimination could put vulnerable customers such as those evaluated in this paper in risk of incrementing its EP levels, with all the associated health and social issues that come with it and that have been discussed in other studies such as [8] and [20].

Finally, it must be remembered that EP is not only a problem for those households that presented EPR_{elect} close or above 10%. As discussed in [8], many EP-affected users have abnormally low consumption as a response to restriction strategies to cope with their fear of facing unpayable electricity bills, which lowers their EPR_{elect} values. Other households use other fuels whose cost must be contemplated for comparison against the 2M threshold.

5. Acknowledgement

This research is part of the EmpowerMed project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 847052. Researchers from IREC have been partially supported by the Generalitat de Catalunya (2017 SGR 1219).

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Data Statement

The datasets analysed during the current study are not available due to data protection regulations but the authors will make every reasonable effort to publish them in near future in anonymized way.