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Analysing the Drivers of Electricity Demand in Spain After the Economic Crisis

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Abstract: Electricity provides a crucial service in our daily lives. However, in electricity systems mostly based on conventional, fossil-fuel fired technologies, an increase in electricity demand also leads to higher greenhouse gas emissions and, in countries without fossil-fuel resources, also increases their dependence on foreign energy sources. In more decarbonised electricity systems, with a high penetration of variable renewable energy sources, strong increases in electricity demand lead to higher system costs, given the need for back-up. Therefore, identifying the drivers of electricity demand is an academically-relevant, but also a policy-relevant exercise, since specific policy measures can be linked to those drivers. The aim of this paper is to assess the drivers of electricity demand in Spain in the period immediately after the economic crisis (2013–2017), with the help of a unique database of Spanish households and econometric modeling. Our results show that electricity demand in this period has mostly been driven by price changes. Demand has been highly price-elastic, with price elasticities being much higher (in absolute values) than in previous studies and periods. It is also negatively driven by the features of the household and its breadwinners (whether they are single-parent households or its members are foreign residents) and positively driven by income, the hours of sun and temperature changes, although the influence of these variables is much lower. In contrast, other variables do not seem to have an influence on demand, including the age of the breadwinners and their working situation (whether they are unemployed or not). These results suggest that price-based instruments, i.e., measures with an impact on electricity prices, would be the most effective to curb electricity demand.

Keywords: electricity demand; Spain; econometric modeling; households

1. Introduction

Climate change represents one of the world's greatest challenges. The emissions of greenhouse gases need to be cut and there is a widespread consensus on the need for a decarbonised energy transition. This requires the involvement of different types of actors (energy producers and consumers) as well as the adoption of different types of measures for different energy uses (electricity, transport and heating/cooling). Deployment of renewable energy technologies and energy efficiency measures which tackle different sectors (industry, transport, energy production and residential) stand out in this context. An energy transition cannot progress without the involvement of energy consumers, and particularly households.

Households use energy for various purposes: space and water heating, space cooling, cooking, lighting and electrical appliances and other end-uses, which mainly cover uses of energy by households outside the dwellings themselves. As a result, their share in total electricity demand is considerable. The residential sector accounted for nearly a third of world energy consumption and 25.4% of final energy consumption in the EU in 2016 [1].

In turn, electricity represents 24.5% of the EU final energy consumption (FEC) in the residential sector in the EU, although this percentage can be as high as 40% in some countries, such as Spain. Electricity used for lighting and most electrical appliances represents 13.8% of FEC in the EU and this percentage is as high as 29% in Spain. In this country, electricity represents 6.7%, 15.5% and 47% of all energy used for heating, water heating and cooking, respectively [1]. All the energy used for air conditioning and lighting in Spain is covered by electricity.

Therefore, electricity provides a crucial service in our daily lives. However, in electricity systems mostly based on conventional, fossil-fuel fired technologies, an increase in electricity demand also leads to higher emissions of greenhouse gases and local pollutants and, in countries without fossil-fuel resources, it also increases their dependence on foreign energy sources. In more decarbonised electricity systems, with a high penetration of variable renewable energy sources, strong increases in electricity demand result in higher system costs, given the need for back-up. Therefore, identifying the drivers of electricity demand is an academically-relevant, but also a policy-relevant exercise, since specific policy measures can be linked to those drivers.

The aim of this paper is to assess the drivers of electricity demand in Spain in the period immediately after the economic crisis (2013–2017) with the help of a unique database of Spanish households and econometric modeling.

Accordingly, the paper is structured as follows: The next section reviews the literature on electricity demand, with a focus on previous studies carried out in Spain. Sections 3 and 4 describe the model used in this paper and the data, respectively. The results of the econometric analysis are provided and discussed in Section 5. Section 6 presents our conclusions.

2. Literature Review

There are many studies on residential electricity demand and multiple variables have been used in the analyses to explain such demand. The determinants of household electricity consumption have been investigated extensively at a macroeconomic level [2–8]. At a microeconomic level, several studies have shown that household electricity demand is influenced by socio-economic and demographic characteristics [9–17], location [18–21], climate and environment [20,22–26], dwelling characteristics [13,15,27,28] and consumer behavior [29,30].

A relevant distinction between models with aggregate and disaggregate data can be made, and each have advantages and drawbacks [28]. Good historical statistics, but only for a limited number of variables, are typically available at the aggregate level. Thus, only a few variables can be included in studies with aggregate data, resulting in a loss of individual behavior-related information [31–33]. In general, studies with disaggregated data are based on more detailed information about households. Nonetheless, these data are mostly cross-sectional, which makes it difficult to assess the effect of price fluctuations on consumption [28]. Household-level panel data are mostly used to analyse the price elasticity of electricity demand [34]. In the absence of complete panel details, some experiments build pseudo-panels and base their study on a collection of independent data [6,33].

The analysis of price and income elasticities is influenced by regulations, pricing models, type of consumers, econometric methods and other factors. Commonly, household electricity consumption is estimated as price- and income-inelastic, but a diversity of results is provided in the literature [32,35–37]. In most OCDE countries, income seems to have a relatively small positive impact on electricity demand, and elasticities below 0.10 are common [15,16,20,35,38]. However, values about 0.3 are also widespread, according to the review carried out in [2].

Studies on the price elasticity of demand vary with the kind of elasticity being considered. The literature focuses mainly on short-term elasticity because more data is needed on long-term elasticity [39]. In the short term, the consumer can react to a price change only by modifying his/her electricity consumption. This is why short-term elasticity values have been found to be lower than long-term elasticities because, in the long-term, the user can respond to increases in prices by, for example, improving the conditions of the dwelling or acquiring energy-efficient appliances [33,39].

Price elasticity results for energy demand range from −0.4 to −0.2 for the short, and from −0.7 to −0.5 for the long term [32,37,40]. Some studies [37,41] have found a wider range of values for price elasticities (see [2]), that could be caused by different aggregation of the data, the use of different econometric methods and different time frames [42,43].

The calculation of price elasticities has been based on different econometric methods in the past: Ordinary Least Squares (OLS) [44]; Least Squares Dummy Variable (LSDV) and Least Squares Dummy Variable Corrected (LSDVC) [36,39]; robust statistic regression [45]; Fixed Effects (FE) and Random Effects (RE) models [6]; Pooled Mean Group (PMG) when using panel data [46]; or Generalized Least Square (GLS) [38]. Methods to calculate the price elasticity of demand differ in terms of the model of energy demand.

Lagged demand and error correlation, and miscalculation in the average price of energy (due to wrong measures), are some of the common econometric problems which have been found when using dynamic adjustment electricity demand models [47]. Such problems give rise to inconsistent LSDV and GLS estimators [38]. Several scholars have built estimators in order to cope with them [48–50].

Previous Research for Spain

Several research studies were published with the aim of highlighting some of the characteristics of Spanish demand for residential electricity. The academic literature has focused on the estimation of average price and income impacts on electricity residential demand. Previous research has relied on panel data, whether aggregated [2,24] or disaggregated data [33], and the results obtained are consistent with the international empirical evidence on the topic. The demand for electricity is found to be more sensitive to changes in income than to price changes. Price elasticity results for energy demand range from −0.07 to −0.26 for the short, and from −0.19 to −0.37 for the long term [2,24,33]. The income elasticities found range between 0.23 and 0.31 in the short term, and 0.43 and 0.71 in the long term.

The effect of other variables on electricity demand has received special attention. The findings show that electricity demand is positively and significantly related to electricity demand in the previous year, income, weather conditions, population, dwelling size, penetration of electric water heating in households and gas penetration. And it is significantly and negatively related to electricity prices, gas prices, penetration of electric heating in households and the presence of older people in the household [2,24,51,52]. Furthermore, other determinants of electricity demand have been assessed, including the occupancy of homes [5,7], types of consumers, cultural and consumption habits [52,53], energy source and type of buildings [52], use of efficient appliances [53] and the economic crisis and changes in welfare [51].

3. The Model

We use the following linear model to estimate the demand of electricity in Spain in the period 2013–2017:

$$\begin{aligned} lng_{it} = \alpha_i + \beta_1 lnp_{it} + \beta_2 lnI_{it} + \beta_3 lnh_{it} + \beta_4 lnt_{it} + \beta_5 old + \beta_6 age + \beta_7 lnu_{it} \\ + \beta_8 lnf_{it} + \beta_9 lnm_{it} + \beta_{10} trend + \varepsilon_{it} \end{aligned} \quad (1)$$

where g refers to electricity consumption, p is the price of electricity, I is income, h are the annual hours of sun, t is the average annual temperature, *age* is the median age of the population, *old* is the percentage of the population above 65 years, u is the unemployment rate, f is the percentage of foreign residents and m is the percentage of single-parent families. A trend variable has also been included (*trend*), which captures the existence of habit in electricity consumption. All the variables are expressed in logarithms and, thus, the different estimated values of the parameters β_i can be interpreted as elasticities. Finally, ε is the error term which can be decomposed into a fixed effect (μ_i)

and an idiosyncratic error term (v_{it}). In this paper, we assume that the fixed effect is not correlated with the vector of covariates, which allows us to estimate the model through random effects. Table 1 shows the expected sign of the estimated coefficients, which indicates their positive or negative influence on electricity demand.

Table 1. Explanatory variables included in the model and their expected influence on electricity demand.

Variable	Expected Influence on Dependent Variable (Electricity Demand)
Price	(−)
Income	(+)
Hours of sun	(?)
Temperature	(+)
Age	(?)
Old (people > 65years old)	(?)
Unemployment rate	(+)
Foreigner	(+)
Single-parent households	(−)
Trend	(?)

The influence of some variables on electricity demand is straightforward, according to economic theory and the existing literature. Price and income can be expected to affect electricity demand in a negative and a positive manner, respectively (see previous section). Temperature is also a clear case: the higher the temperature, the higher the need for air conditioning, which pushes up electricity consumption. Since unemployed people would tend to stay at home compared to workers, they could be expected to consume more electricity and, thus, a higher share of unemployed people would result in higher levels of electricity consumption. Finally, single-parent households, i.e., households with only one breadwinner, would possibly have lower levels of electricity demand compared to bi-parental ones. The reason is twofold: a size effect and an income effect. On the one hand, single-parent households obviously have fewer members than bi-parental ones. On the other hand, they only have one source of income, whereas there can be two sources in bi-parental households. Indeed, single-parent houses have a greater risk of poverty or social exclusion. A lower income level implies a lower level of electricity consumption, ceteris paribus.

However, the expected sign for other variables is not so clear. This is the case with the hours of sun. On the one hand, in places with more hours of sun, a greater exposure to sunlight can be expected. This tends to heat houses to a greater extent and, thus, more air conditioning would be needed. However, this need for air conditioning is captured in the temperature variable. On the other hand, more hours of sun imply less need for electric lighting. In addition, it can be expected that people make more outdoor activities in sunny days compared to cloudy and rainy ones. Therefore, these two effects oppose each other and, a priori, we cannot tell which one would dominate. This is mostly an empirical issue.

The effects of age and the presence of old people in the household are also unclear a priori. As argued by [2], although older people are likely to use some electric devices more intensively (TV), the younger members in the households may make more use of others (i.e., computers). Reference [13] argued that the highest levels of electricity demand occur when the breadwinners are between 36–55 years old, due to the presence of children.

Finally, the trend variable captures habit in electricity consumption, which is due to inertia in electricity consumption [54,55]. However, this trend variable may include other effects, such as changes in electric-efficient technologies, more electric efficient behaviours and the impacts of policies.

4. The Data

Table 2 describes the sources of data for the different variables. The electricity consumption data come from the information provided by the local utilities that supply the 259 municipalities considered in this study, which are spread over 45 Spanish provinces. The available data include the electricity consumption (in kWh) and the contracted power (in kW) of 17,190 homes in the period 2013 to 2017.

Table 2. Description of data sources.

Variable	Description	Source	Obs/Year
Energy	Electricity consumed by householders (kWh)	Local utilities	17190
Price	Real average price of electricity (€/kWh)	EUROSTAT	5
Income	Households average disposable income (€)	Ministry of Economy and Finance (AEAT)	259
Hours of sun	Regional annual hours of sunlight (h)	State Meteorology Agency (AEMET)	45
Temperature	Regional average annual temperature (°C)	State Meteorology Agency (AEMET)	45
Age	Median age of the population (years)	National Institute of Statistics (INE)	259
Old people > 65 years	Population over 65 years (%)	National Institute of Statistics (INE)	259
Unemployment rate	Unemployment rate (%)	State Employment Service (SEPE)	259
Single-parent households	Single-parent households (%)	National Institute of Statistics (INE)	259
Foreign	Foreign residents in relation to the whole population (%)	National Institute of Statistics (INE)	259

The evolution of final electricity consumption for residential uses in Spain experienced a sustained increase between 1990 and 2011 and, then, decreased (Figure 1). This was probably due to the economic crisis and the use of more efficient appliances. There has been an upward trend after 2016, which can be explained by the adoption of new appliances as a result of higher incomes. These appliances lead to an increase in electricity consumption levels, even if efficiency measures are maintained. Our sample data is consistent with this tendency, although an increase is not observed in 2017 (Table 3).

Table 3. Evolution of electricity consumption (kWh/year).

ENERGY	Obs	Mean	Std. Dev.	Min	Max
2013	259	3787.207	2202.298	12.4	18,237.12
2014	259	3525.567	1594.488	243.4	13,008.70
2015	259	3639.915	1625.823	83.3	13,216.09
2016	259	3685.279	1439.803	923.2	12,592.19
2017	259	3544.546	1523.168	594.1	15,680.65

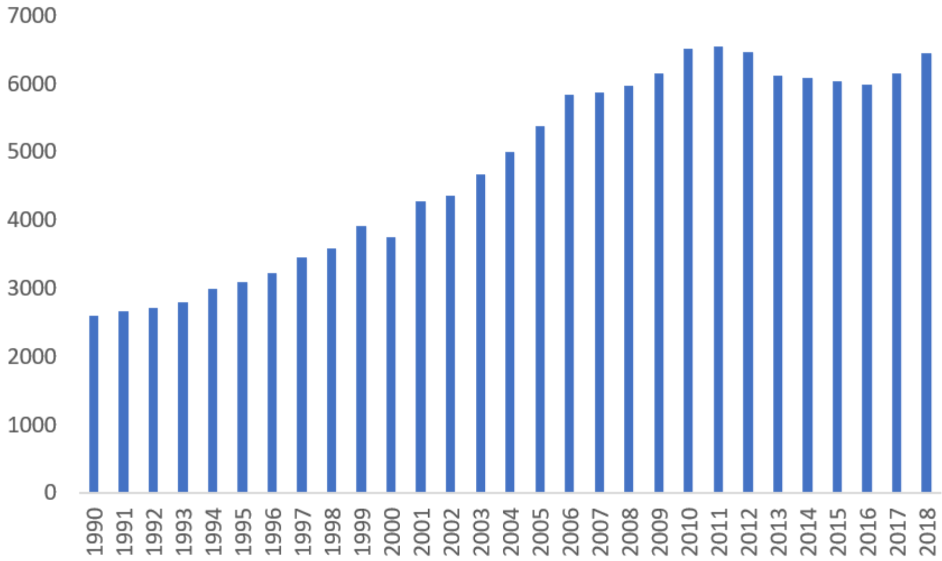

Figure 1. Final electricity consumption (thousand tonnes of oil equivalent, ktoe) [56].

It is important to take into account the particularities of the period chosen for this study with respect to the previous and the recent ones.

With respect to the years before 2013, higher GDP growth rates, lower electricity demand levels and higher electricity retail prices could be observed during this period. Annual GDP growth rates in Spain in the period considered in this study were relatively high, particularly by the end of the period. GDP grew by 2.89% in 2017, 3.03% in 2016 and 3.84% in 2015, although only by 1.38% in 2014. It went down by 1.44% in 2013, the last year of the economic recession. The GDP growth rates were negative in the 2009–2012 period, whereas they were between 3% and 4% in the previous 10 years. The growth rates in the analysed period were also higher than those observed in recent years (2.4% in 2018 and 2% in 2019).

Electricity demand remained at the levels of the years before the crisis and went down slightly during the analysed period, although it experienced a considerable increase in 2017. The context which influences electricity demand has changed in the analysed period compared to the previous and the current one. Regarding the period before 2012, there was a constant increase in residential electricity consumption, which ended in 2010. Then, the crisis led to stagnant consumption between 2010 and 2012. In 2012, the weight of electricity demand in residential energy was 42%. The detrimental effects of the crisis became stronger in 2013. By the end of the analysed period (2013–2017), electricity consumption in the residential sector was 6% lower compared to the initial year of this period. This reduction was due to the crisis, but also to the improvement of the energy efficiency of the installations (air-conditioning and electric devices) and the penetration of renewable energy sources (self-consumption and biomass for residential uses). Finally, after 2018, electricity consumption increased and reached the levels recorded before 2013. A special mention should be made to the impact of COVID, which has led to a 4% increase in residential electricity demand during the lockdown.

From the perspective of the electricity consumer, important changes for the electricity consumer regarding contractual conditions and electricity prices have been experienced in the analysed period compared to previous ones. It is important to take into account that the liberalisation of the electricity sector progressed in the period, particularly at the residential level. This progress had already taken place in the industrial and SME (small-and-medium size enterprise) segments. The liberalization of the electricity sector started in 1998 for large consumers.

In 2003, all consumers had the right to freely contract in the market, although regulated "integral" tariffs also applied. Those regulated tariffs disappeared in 2009 and only consumers with contracted capacities below 10 kW could benefit from the last-resort tariff (also known as PVPC). This hourly tariff was (and still is) regulated by the government. In 2019, 59% of residential consumers had contracts in the free market. The final electricity price paid by the consumer has three main components: the production cost (which includes the price of electricity in the wholesale electricity market plus the estimated costs of the services provided by the system operator and the remuneration of the market and system operators, among others), the access tariffs for the use of electricity grids (which is published by the government) and other costs (which include the electricity tax, the rental of the measuring equipment, the value added tax and the benefit for the distribution company).

During the analysed period, the number of residential clients slightly increased and reached 27 million. 42% of residential clients had contracted in the free market in 2013, and this percentage increased to 58% in 2017 and 59% in 2018. This increase was due to the entry of new electricity retailers in the market. The number of electricity retailer companies increased from 113 in 2013 to 273 in 2017.

Average electricity prices increased by 12.7% between 2013 and 2017 for consumers with contracted capacities below 10 kW, and by 5.4% for contracted capacities above 10kW. The average level of the electricity prices in 2013–2017 increased substantially with respect to the average prices in previous periods (between 6% and 34%, depending on the consumption band) (see the supplementary material for details). Residential electricity prices have continued to increase after 2017 (Table 4).

Table 4. Residential electricity prices in Spain (€/kWh, all taxes and levies included).

Consumption Segment (DC Band)	2 Semester 2017	1 Semester 2018	2 Semester 2018	1 Semester 2019	2 Semester 2019
<1000 kW	0.5696	0.5952	0.5704	0.657	0.5607
1000–2500 kW	0.2687	0.2929	0.3044	0.2995	0.2953
2500–5000 kW	0.2177	0.2383	0.2477	0.2403	0.2394

Source: [57].

The data on the socioeconomic variables used in this study are aggregated per municipality. Therefore, first, we calculate the consumption and price, in each year of the study, for the average consumer in the 259 municipalities. This average consumer is assumed to have a consumption which is equivalent to the average consumption level in the municipality.

The price is calculated as the total electricity costs of the municipality divided by the total energy consumed in the municipality. We first calculate the cost of each of the 17,190 observations in the years of the study, which results from multiplying the consumption of the observation by the assigned electricity price. This leads to an average electricity cost in the 259 municipalities. We then allocate a price to each of the 17,190 observations, in every year, using as proxy the electricity prices for household consumers (bi-annual data). These prices are available for 5 consumption ranges and are provided by Eurostat [57] for Spain. This is affected by the electricity price index and weighted by the consumer price index (CPI) of each region, both provided by the National Institute of Statistics (INE), to avoid the low regional diversity of the average electricity due to the tariff structure used in Spain.

With this process, an average price has been obtained for every municipality. The whole electricity expense in the municipality has been calculated, adding the expense of every observation located in the same municipality and dividing it by the whole consumption in the municipality.

Stability in prices has been maintained along the studied period (Table 5), and the differences found are explained by the differences in the power contracted (below 15 kW in this study), and by different levels of energy consumed (Table 3). For the econometric estimation, an average electricity household price (with an index base 2013 equal to 100) has been used.

Table 5. Evolution of the electricity price for households (€/kWh).

PRICE	Obs	Mean	Std. Dev.	Min	Max
2013	259	0.265341	0.031772	0.210705	0.447595
2014	259	0.271422	0.033640	0.209074	0.550958
2015	259	0.264658	0.040986	0.212130	0.566407
2016	259	0.249630	0.022176	0.198445	0.401644
2017	259	0.257415	0.036822	0.175355	0.630698

The 259 data employed for the income variable in every municipality have been obtained from the Ministry of Economy and Finance (AEAT). A gradual increase can be observed (Table 6).

Table 6. Evolution of disposable income (€/year).

INCOME	Obs	Mean	Std. Dev.	Min	Max
2013	259	19,913.46	4218.526	13,531	53,974
2014	259	19,906.75	4493.023	13,063	59,622
2015	259	20,681.68	4837.936	13,774	60,946
2016	259	21,111.23	4953.034	13,815	62,248
2017	259	21,524.02	5077.957	14,180	63,590

Socioeconomic variables are included in the model in order to capture the impact on electricity demand. Data on the unemployment rate, the share of population over 65 years, the median age of the population, and the percentage of foreign residents in relation to the whole population are obtained for every municipality.

The effect of climate on electricity demand is measured with data provided by the State Meteorology Agency which calculates the average temperature in a province by collecting data on temperature in different sites in the same province and annual hours of sunlight in the province. In this research, values of the province are considered as values for the municipalities of the same province. The following maps show average annual levels of the number of hours (Figure 2) and temperature (Figure 3) per province. It can be observed that both average radiation levels and temperatures are highest in the south and east, and lowest in the north and west.

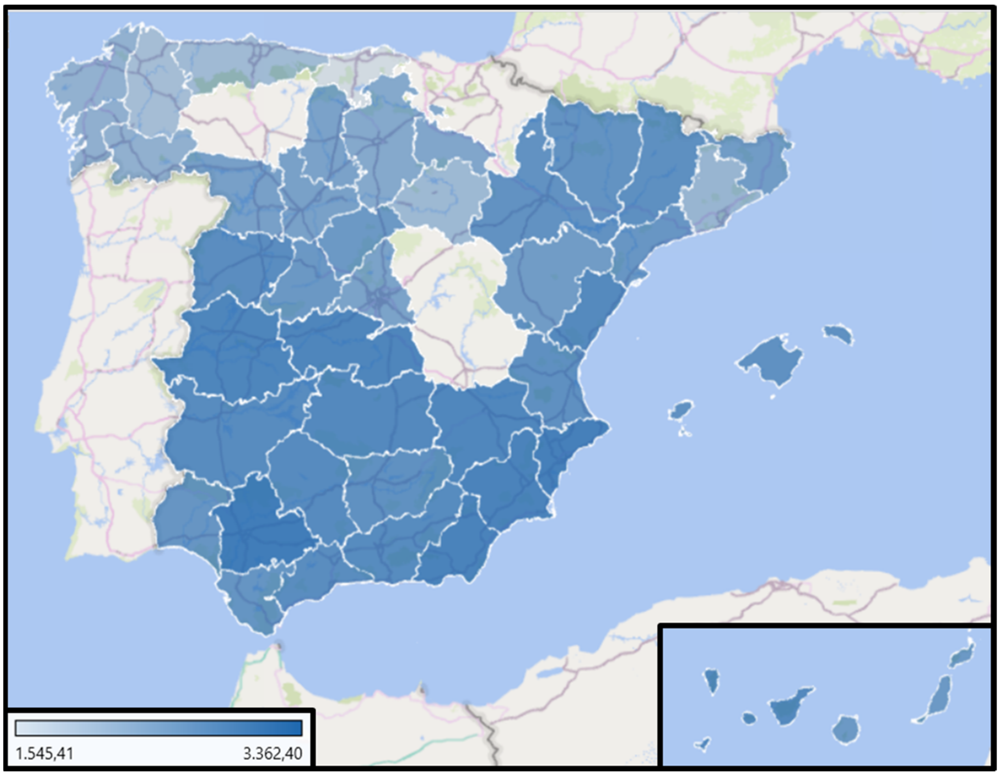

Figure 2. Average number of hours of sun per year and province (Own elaboration).

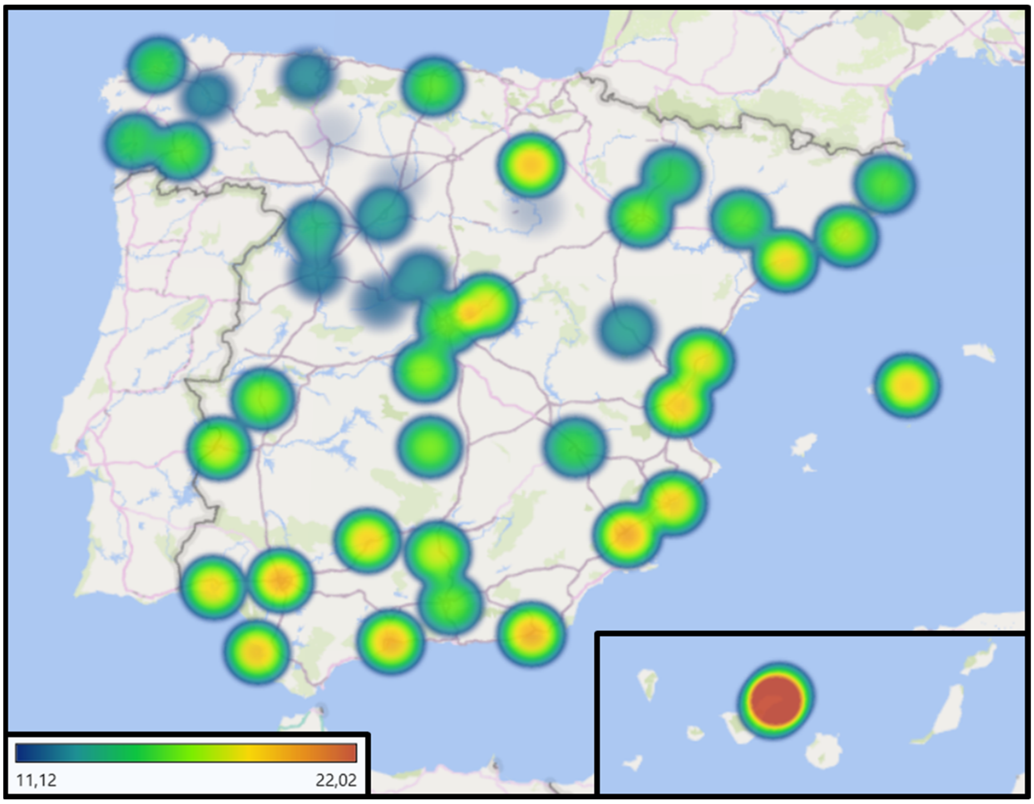

Figure 3. Average annual temperatures per province (Own elaboration).

5. Results and Discussion

The choice of the estimator used (see Equation (1)) has been conditioned by three key factors: (i) the exogenous variables which are available in order to estimate the demand; (ii) the short longitudinal dimension of the available panel data (T) and; (iii) the possible existence of endogeneity in the model. The linear model used (see Equation (1)) includes virtually all the variables which are commonly used in the literature on electricity demand. However, some variables which could have been relevant to explain electricity demand have not been included in the model due to the lack of sufficiently disaggregated data. One of these variables is the number of households with air conditioning devices. In this case, we have included a trend in order to avoid the bias in the estimated parameters which could be caused by the existence of omitted variables. Unfortunately, other variables, such as the number of households in each municipality, have not been included because accurate information is not available. The fixed-effects estimator gets round the problems caused by the possible existence of omitted variables which are related to the lack of data or, as it is the case with preferences, because they are not directly observable [58].

Despite its enormous popularity, the fixed-effects estimators have some important limitations which should not be ignored in empirical studies [59]. One of its drawbacks is its lack of precision when the time dimension is very small. This is exactly our case, because we only have a panel of 5 years. For this reason, the random effects two-stage (RE-2SLS) estimator has been used to estimate the model. It corrects the possible existence of endogeneity with respect to the prices and income. Endogeneity problems occur if the changes in electricity consumption and those two variables take place simultaneously. A second problem related to endogeneity is the existence of a measurement error for the income variable. The information on this variable is based on the individual personal income tax declarations submitted to the tax agency. The average value of such variable does not include the income obtained by taxpayers who are not obliged to pay taxes (i.e., those with an annual income below 22,000€). Therefore, the income variable is less appropriately measured in those municipalities with a greater share of people who do not have to pay taxes. This would lead to biased estimations of the parameters of the affected variables.

An OLS estimation is provided for illustrative purposes in columns 1 and 2. Column 3 shows the results for the RE-2SLS estimator, which only includes the price and income variables, with price being the only endogenous variable. Column 4 provides the estimations for the whole model. The variable OLD is excluded, given its non-statistical significance in the three previous estimations, i.e., assuming that the prices are endogenous. Column 5 replicates the estimation assuming that prices and income are endogenous. A lag of the instrumental variables has been used as an instrument in all the cases.

As it can be observed, the parameter β_1 is clearly lower in the estimation with instrumental variables than in the OLS estimation. In any case, the goodness of fit is acceptable, and the null hypothesis that the parameters are not jointly statistically significant can be rejected.

The results of the econometric estimations are provided in Table 7. They show that all the variables have the expected signs and the most relevant ones are statistically significant.

Several variables have had a statistically significant influence on electricity demand in the analysed period. Electricity prices have had the greatest (negative) influence in this context. Electricity demand is also positively driven by income, the hours of sun and temperature changes.

The negative and large coefficient for the price variable (−1.2) suggests a very high price elasticity of electricity demand (in absolute terms), substantially higher than in previous studies carried out for this country in different periods. The price elasticity in [33], for the period 2005–2007, was –0.25, whereas [2] estimates a price elasticity of −0.26 (short-run) and −0.37 (long-run), also for the 1998–2009 period. In their model estimated for the 1998–2009 period, [24] reported price elasticities in the range of −0.07 to 0.19. A possible reason for the much higher price elasticity in our estimation may be the much higher retail electricity price in the analysed period, compared to previous ones (see Section 4 and supplementary material). With higher retail prices, electricity consumers are more reactive to increases in those prices than with lower levels, simply because they have more incentives to save on what is already perceived as a high economic burden for them.

However, the price elasticity of demand is within the range of estimations in the literature for OECD countries (0.2 to −1.2 for short-run elasticities and 0 to −1.6 for long-run elasticities, according to [4]), although in the lower part of such range.

The statistical significance of income, the hours of sun and temperature changes suggest that they have had a (positive) impact on electricity demand, although with a much lower influence compared to prices.

An increase in income leads to higher levels of electricity demand, suggesting that electricity is a normal good. The size of the coefficient (0.44) indicates a non-negligible albeit less than proportional effect. It is lower than the 0.7 income elasticity estimated in [33] and in the middle of the range of 0.23 to 0.61 estimated in [24]. However, it is in the middle of the estimates for other OECD countries [2].

Nevertheless, as warned by ([2], p.10), the comparison between elasticities has to be done with caution since the level of those elasticities depends on the models being used (static vs. dynamic), the type of data (macro vs. micro), the stage of the economic cycle of the period being analysed (expansion or recession), the degree of economic development of the countries or the econometric techniques being used.

The variable "hours of sun" is statistically significant and its coefficient is also positive, although relatively small, suggesting a modest influence on electricity demand. This is related to the aforementioned "more air conditioning" and "less lighting" effects partially offsetting each other, although the first effect seems to dominate the latter one. The impact of air conditioning is clearly captured by the temperature variable, whose statistical significance and positive (although small) coefficient suggests a positive impact on electricity demand. Only high temperatures have a positive impact on electricity demand, related to cooling, since heating is non-electric and, therefore, low temperatures do not have an influence on electricity demand. This result on the influence of temperature is in line with the literature, which is generally measured through heating degree days (HDD).

On the other hand, apart from prices, three other variables are statistically significant and have a negative coefficient (single-parent, foreign and trend). The negative sign for single-parent households was expected (see Section 4). The results for the foreign variable indicate that foreign residents have lower levels of electricity demand than domestic ones. It is difficult to interpret this result. On the one hand, it could mean that foreign residents are more energy efficient than national ones for whatever reason (greater environmental awareness, more responsive to the high retail prices that exist in Spain compared to their country of origin etc.). It could also imply a lower purchasing power of foreign residents. Further research could be devoted to the analysis of this result. The statistical significance and negative sign of the trend variable (although with a very small coefficient) indicates a tendency towards long-term reductions of electricity demand. However, this variable can capture the influence of several variables: technological change (a tendency towards more electric-efficient technologies), more electric-efficient consumer behavior or the impact of electric-efficiency policies which, in turn, affect the other two aspects (technological and behavioural changes).

In contrast, other variables have not had a statistically significant influence on demand, including the age of the breadwinners and their working situation (whether they are unemployed or not). Table 7 contains a diagnosis of the model estimation. The joint significance test rejects the null hypothesis that all the estimated parameters are equal to zero. Furthermore, the under-identification Kleibergen–Paap Wald test is shown (see [60]). Its null hypothesis is that the instrumented variables are not correlated with the instruments. As it can be observed, the null hypothesis is strongly rejected. On the other hand, we provide the results of the weak identification test of the instrumental variables (the Wald test proposed by [60]). The critical values tabulated by [61] are shown. The null hypothesis is rejected in all the estimations and, thus, we can conclude that the instruments used are valid.

Table 8 provides the robustness analysis, extending the estimations of columns 4 and 5 of Table 7. Different lags of prices and income have been used in order to analyse whether the conclusions on the behaviour of consumers (which is affected by income and price changes) are maintained when they refer to a longer period. More specifically, columns 6 and 7 include one and two lags in prices, respectively. On the other hand, columns 8 and 9 include one and two lags both in the price and income variables. The main conclusion is that the high price elasticity of demand shown in Table 7 is even higher when one or two lags are included. This is an expected result and suggests that the response to prices is more elastic in the long-term than in the short-term. In contrast, the income elasticity is lower. This indicates that electricity demand is less dependent on income changes in the long-term.

Table 7. Estimations.

		OLS (1)		OLS (2)		RE-2SLS (3)		RE-2SLS (4)		RE-2SLS (5)	
		SIMPLE		REF		Simple endogeneity in prices		Endogenous prices		Endogenous income and prices	
Price	Coef.	−1.4450	***	−1.4758	***	−1.1911	***	−1.2130	***	−1.2115	***
	RSE	0.1620		0.1590		0.2370		0.2541		0.2545	
Income	Coef.	0.2422	***	0.5401	***	0.1640	**	0.4243	***	0.4061	***
	RSE	0.0830		0.1480		0.0700		0.1106		0.1115	
Hours of sun	Coef.			0.2009	***			0.2696	***	0.2688	***
	RSE			0.0690				0.0666		0.0668	
Temperature	Coef.			0.2820	***			0.2181	*	0.2187	*
	RSE			0.1050				0.1122		0.1124	
Age	Coef.			−0.2903				−0.3383		−0.3331	
	RSE			0.5100				0.3793		0.3801	
Old	Coef.			0.0070							
	RSE			0.1160							
Unemploy	Coef.			0.1405				0.0815		0.0745	
	RSE			0.0940				0.0958		0.0955	
Foreign	Coef.			−0.0782	***			−0.0804	***	−0.0810	***
	RSE			0.0270				0.0272		0.0271	
Single	Coef.			−0.0782				−0.0775		−0.0782	
	RSE			0.0860				0.0852		0.0853	
Trend	Coef.			−0.0388				−0.0848	*	−0.0856	*
	RSE			0.0420				0.0502		0.0503	
_cons	Coef.	12.3508	***	8.8999	***	11.9569	***	8.6444	***	8.7960	***
	RSE	1.0460		2.0940		1.4380		1.5659		1.5642	
Observations		1295		1295		1036		1036		1036	
DIAGNOSIS											
Joint-significant test		F(2, 1292) = 43.45 ***		F(10, 1284) = 20.49 ***		F(2, 1033) = 19.60 ***		F(9, 1026) = 23.04 ***		F(9, 1026) = 22.34 ***	
Underidentification test (1)		-----		-----		LM = 22.158 ***		LM = 19.198 ***		LM = 19.277 ***	
Weak identification test (2)						Wald = 49.471 ***		Wald = 78.564 ***		Wald = 39.317 ***	

Table 7. *Cont.*

Stock-Yogo weak ID test critical values 10%	-----	-----	7.03	16.38	7.03
15%	-----	-----	4.58	8.96	4.58
20%	-----	-----	3.95	6.66	3.63
INSTRUMENTS					
			Price Lag 1	Price Lag 1	Price/Income Lag 1

(***) Significant at 1% level, (**) significant at 5% level, and (*) significant at 10% level. RSE: Robust Standard Error. (1) Kleibergen-Paap rk LM statistic. (2) Kleibergen-Paap rk Wald F statistic.

Table 8. Robustness check.

		RE-2SLS (6)		**RE-2SLS (7)**		**RE-2SLS (8)**		**RE-2SLS (9)**	
		Endogenous prices		Endogenous prices		Endogenous income and prices		Endogenous income and prices	
Lag 1. Price	Coef.	−1.5277	***			−1.5282	***		
	RSE	0.3343				0.3371			
Lag 2. Price	Coef.			−1.2896	***			−1.2922	***
	RSE			0.4175				0.4214	
Income	Coef.	0.3578	***	0.3323	***				
	RSE	0.0968		0.1094					
Lag 1 Income	Coef.					0.3138	***		
	RSE					0.0978			
Lag 2 Income	Coef.							0.2822	**
	RSE							0.1095	
Hours of sun	Coef.	0.2780	***	0.2321	***	0.2776	***	0.2312	***
	RSE	0.0690		0.0817		0.0692		0.0821	
Temperature	Coef.	0.2324	*	0.2312	*	0.2425	*	0.2469	*
	RSE	0.1303		0.1398		0.1297		0.1386	
Age	Coef.	−0.3567		−0.1620		−0.3414		−0.1428	
	RSE	0.5607		0.4064		0.5599		0.4041	
Unemploy	Coef.	0.0401		0.0718		0.0197		0.0479	
	RSE	0.0817		0.0830		0.0812		0.0810	

Table 8. *Cont.*

Foreign	Coef.	−0.0820	**	−0.0626	**	−0.0836	**	−0.0647	***
	RSE	0.0352		0.0249		0.0352		0.0247	
Single	Coef.	−0.0752		0.0000		−0.0761		−0.0904	
	RSE	0.1296		0.0000		0.1296		0.1076	
Trend	Coef.	−0.2826	***	−0.0902	***	−0.2993	***	−0.4448	***
	RSE	0.0872		0.1077		0.0861		0.1281	
_cons	Coef.	10.9269	***	10.0541	***	11.2852	***	10.4733	***
	RSE	2.5256		2.9368		2.5283		2.9345	
Observations		777		518		777		518	
DIAGNOSIS									
Joint-significant test		F(9, 767) = 13.91 ***		F(9, 508) = 9.19 ***		F(9, 767) = 13.14 ***		F(9, 508) = 8.42 ***	
Underidentification test (1)		LM = 16.769 ***		LM = 6.853 ***		LM = 16.802 ***		LM = 6.854 ***	
Weak identification test (2)		81.685 ***		28.384 ***		40.932 ***		14.183 ***	
Stock-Yogo weak ID test critical values	10%	16.38		16.38		7.03		7.03	
	15%	8.96		8.96		4.58		4.58	
	20%	6.66		6.66		3.95		3.95	
INSTRUMENTS									
		Price Lag 2		Price Lag 3		Price/Income Lag 2		Price/Income Lag 3	

(***) Significance at 1% level, (**) significance at 5% level, and (*) significance at 10% level. RSE: Robust Standard Error. (1) Kleibergen-Paap rk LM statistic. (2) Kleibergen-Paap rk Wald F statistic.

6. Conclusions

This paper has identified the drivers of electricity demand in Spain in the period immediately after the economic crisis (2013–2017) with the help of a unique database on Spanish households and econometric modeling. Households will be a crucial element in achieving a decarbonised energy transition, since this depends on the micro decisions on energy use taken by consumers. In this context, electricity use is a critical element of overall energy consumption, and it should be the target of policy measures aimed at encouraging a more efficient use of electricity, particularly in the residential sector.

Our results show that electricity demand in this period has mostly been driven by price changes. Demand has been highly price-elastic, with price elasticities being much higher than in previous studies and periods. It is also negatively driven by the features of the household and its breadwinners (whether they are single-parent households or its members are foreign residents) and positively driven by income, the hours of sun and temperature changes, although the influence of these variables is much lower. In contrast, other variables do not seem to have an influence on demand, including the age of the breadwinners and their working situation (whether they are unemployed or not).

These results are in contrast to the studies carried out before the economic crisis (2009-2013), which indicate a very low price-elasticity of demand (and a relatively high income-elasticity of demand, see Section 2). However, in our opinion, the finding on the distinct price elasticity of demand in different periods is less related to the economic crisis and more related to the high and increasing retail electricity prices paid by consumers (see Section 4 and the supplementary material), which are affected by the higher wholesale electricity prices as well as the regulated component of those prices (the costs of promotion of renewable energy sources, the increase in distribution costs and the payment of the interest rates for the accumulated debt in the system, see [2]). Since electricity prices have continued to increase in recent years, this conclusion would still hold.

These results suggest that price-based instruments, i.e., measures with an impact on electricity prices such as taxes, would be the most effective to curb electricity demand. However, an increase in electricity prices, while effective to curb electricity demand (according to our results), brings other problems, especially in a country where those prices are already very high. In addition to being politically unfeasible (higher prices do not win votes), it aggravates energy poverty, which is already relatively high in Spain and has detrimental effects on the industrial competitiveness of the economy. Therefore, a difficult trade-off between the positive effects of electricity demand reductions and other policy objectives exists and balances have to be found. Further research should be devoted to the analysis of those trade-offs and the policy mix which would balance them, knowing that any single measure leads to undesirable side-effects.

Other policy measures (information provision), while less effective to reduce electricity demand (according to our findings) would not lead to the aforementioned trade-offs and, thus, would be more palatable from a political point of view. This suggests a main role to be played by the local authorities, which are usually the closest to the day-to-day decisions of households, i.e., of residential electricity consumers. Information and education campaigns would be more effective if implemented at this level.

Improving the energy efficiency of households and encouraging the deployment of renewable energy at low costs in the residential segment (PV self-consumption installations) should be key policy priorities. This suggests that fiscal and financial measures which directly benefit the residential consumer should be implemented, including subsidies or rebates for investors in self-consumption equipment as well as for the improvement of the efficiency of buildings and electronic devices. These measures could be channeled through electricity retailer companies. Agreements with distribution companies could be adopted for the promotion of energy efficiency in schools through the inclusion of this concept in curricular contents and informative talks.

It should be mentioned that the energy consumption data provided by one of the main energy electricity retailer companies in Spain and used in this study offer a valuable input to analyse demand. Unfortunately, the time coverage of the data is limited and restricted to the period 2013–2017.

Several avenues for further research are worth exploring in the future. First, despite the temporal limitation of our data, they can be used to analyse the efficiency of household electricity consumption using stochastic frontiers. Second, while this paper has assessed the drivers of electricity consumption for all types of households and consumption, an analysis of the drivers per type of electricity consumption could be carried out in the future. This will allow the identification of differential patterns across different consumer/consumption types.

Supplementary Materials: The following are available online at: www.mdpi.com/xxx, Figure S1: Average electricity prices in the three periods for different consumption bands (€/kWh, nominal prices, all taxes and levies included), Table S2.1: Increase in the average level of electricity prices in 2013-2017, Figure S2: Evolution of electricity prices in Spain and the EU in the <1000 kWh band (€/kWh, nominal prices, all taxes and levies included), Figure S3: Evolution of electricity prices in Spain and the EU in the 1000-2500 kWh band (€/kWh), Figure S4: Evolution of electricity prices in Spain and the EU in the 2500-5000 kWh band (€/kWh), Figure S5: Evolution of electricity prices in Spain and the EU in the 5000-1500 kWh band (€/kWh), Figure S6: Evolution of electricity prices in Spain and the EU in the >15000 kWh band (€/kWh), Table S2: Countries with the highest household electricity prices in the EU in the second semester (S2) of 2017 and position of Spain in the ranking.

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