Energy consumption and urban sprawl: evidence for the Spanish case

Abstract

Electricity accounted for 41,2% of the total final energy consumption of Spanish households in 2014. In Spain, electricity is still generated from fossil fuels, which affects the level of greenhouse gas emissions and Spanish energy dependency. Therefore, policies oriented towards reducing household electricity consumption could help to achieve a more energy-sustainable and low-carbon economy. Some of those policies seek energy building savings from energy rehabilitation of the thermal envelope, the renewal of appliances, or the construction of nearly-zero energy buildings. However, the relevance of urban structure and urban phenomena, such as urban sprawl, has not normally been considered for household electricity savings.

This paper focuses on the impact of urban design and urban sprawl on household electricity consumption. Thus, an electricity consumption model is estimated by using urban characteristics as its determinants, such us the level of urban agglomeration or if the families live in a detached, sprawling house, and also household socioeconomic variables. The model is estimated by using 2014 Household Budget Survey (HBS) microdata and applying Ordinary Least Squares as well as quantile regressions as econometric procedures.

Results confirm that living in a detached house significantly increases the electricity consumption while urban agglomerations have the opposite effect. Sprawl is occurring rapidly in Spanish cities and, according to our results, it could constitute a main source of increase in electricity demand in the following years. This paper comments on the relevance of urban policies and urban planning from the perspective of household energy efficiency.

Keywords: household energy consumption, house characteristics, urban sprawl and urban energy efficiency.

1. Introduction

Currently, 55% of the world's population lives in urban areas, a proportion that is expected to increase to 66% by 2050 and 85% by 2100. In a rapidly urbanizing world, the way in which cities are planned, built, operated and redefined has a huge social and economic impact. Urban poverty, inequalities, affordable housing, mobility and congestion are at the heart of traditional urban challenges. However, the environmental problems of pollution, increased global energy consumption and climate change as well as the energy dependency of many countries draw attention to sustainable urban growth and, particularly, to the understanding of energy consumption patterns in cities, and drive innovation in urban energy savings and green building.

Urban energy efficiency engages a complex and nuanced spectrum of issues. In recent years, one of the main focuses of innovation in cities was placed on the capacity of new technologies to develop “smart cities”, those that are monitored with networks of devices that give precise information about pollution and local mobility, allowing a better understanding of city life and problems. Many scientists are also investigating the use of new materials and building technologies to improve housing energy performance. By contrast, the relevance of energy consumption of urban phenomena, such as urban sprawl, is still not widely studied.

The first cities to begin to experience urban sprawl were the emergent cities of the central and western United States. This model of a sprawling city rapidly extended first to Latin America (see Gilbert 1996 and Polèse and Champain 2003) and later to Asian cities (see Bunnel et al., 2002), finally becoming a global phenomenon. Traditionally, most old European cities grew differently from the new cities of America or Asia: cities on the old continent were strongly concentrated around a densely packed historical centre and its commercial and business extensions and usually adhered to a monocentric growth model with a strong centre and hierarchical structure of sub-centres. However, urban sprawl in Europe has grown in many cases over the last four decades (see Couch et al., 2007). According to the European Commission (2006), countries in the east and south of Europe are the ones most at risk of an explosive process of urban sprawl.

The case of Spain is one of the most interesting in Europe. In some areas of the Iberian Peninsula there is very high building pressure due to tourism and the demand for a second residence. The Spanish economy has been drastically affected by the construction sector suffering one of the biggest real estate bubbles of all of Europe (Romero, 2012). Spain had very fast economic growth during the last four decades of the past century, presenting a very strong, concentrated process of urbanization. Cities such as Madrid and Barcelona doubled their population in less than twenty years. Other big metropolitan areas of the country experienced such growth that different cities or towns grew into one. Rural areas also lost most of their population in just two decades. The strong changes in income per capita, social customs and land use pressures make Spain a victim of sprawled urban growth (Rubiera et al., 2016).

In this paper, we are particularly interested in measuring and evaluating the effect of increasing urban sprawl in Spanish cities on residential energy consumption. Residential energy consumption constitutes one of the largest sources of Spanish final energy demand, 19% in 2014 according to the European Commission (2016). Thus, we are going to focus on electricity consumption as it is the largest source of household energy demand. Electricity accounted for 41,2% of the total final energy consumption in 2014 with an increasing trend (household electricity consumption increased 21,8% from 2004 to 2014, see European Commission, 2016). It should be noted that nearly 72% of Spanish electricity is still generated from fossil fuels (Spanish Government, 2016), which affects the level of greenhouse gas (GHG) emissions and Spanish energy dependency (European Commission, 2016). Therefore, household electricity saving achieves a more energy-sustainable, low-carbon and climate friendly economy. To reduce household energy consumption, it is important to analyse its determinants. Most of the existing empirical works have used local climate, home appliances, household size or household characteristics, among other aspects, as determinants of energy consumption for households. In contrast, this paper focuses this paper focuses on the impact of urban design and urban sprawl on household electricity consumption.

The phenomenon of urban sprawl has been studied within different disciplines (geography, urban planning, the environment, economics, sociology and even public health) and from very different standpoints, which has led to numerous definitions. Glaeser and Kahn (2004) and, more recently, Jaeger and Schwick (2014) have compiled one of the most complete reviews of leading papers on urban sprawl and its consequences. Although all the studies consider urban sprawl as a complex phenomenon having many dimensions, they all coincide in the idea that sprawled cities always denote the extent of the area that is built up and its dispersion in the landscape, the more area built over and the more dispersed the buildings, the higher the degree of urban sprawl. Thus, from the individual point of view (household) sprawl means the predominance of detached houses instead of the building of apartments and low building density. Thus, from the energy consumption perspective, the effect of sprawl could be identified by the effect of living in detached houses in less intensely agglomerated areas.

According to statistical data from the Household Budget Survey of the National Statistical Institute, in 2014, approximately 35% of the population of Spain lived in houses, with 11% living in detached houses and 24.2% in semi-detached houses (INE, 2014). The remaining percentage of the population is distributed among other types of houses, such as flats. What we propose in this paper is to study energy consumption factors of households, including in the analysis the urban environment (urban size and urban versus rural areas) and the type of house to identify how they affect energy consumption. The obtained results could orient state and local governments in energy efficiency strategies of urban planning. A more electricity efficient urban design can not only decrease the energy dependency of the Spanish economy and achieve energy savings but also improve the environment by reducing GHG emissions and help to fulfil the EU's 2020 and 2030 climate and energy goals (Council of the European Union, 2010, 2014).

The paper is structured as follows. In the next section, we review the empirical models of energy consumption and their previous conclusions, focusing on those papers that particularly include in some way the urban/rural effect and housing characteristics. From this literature review we obtain the household electricity model specification to be estimated. Section three revises the dataset, the Household Budget Survey (INE, 2014) and specific characteristics of the Spanish case. The estimation strategy and main results are presented in section four. The main conclusions are summarized in the final section, along with a number of recommendations regarding policy.

2. Household energy consumption in urban areas: literature review and empirical model proposal

The effect of several variables on household energy consumption has been widely studied. Previous studies have found that household energy consumption could be explained by various factors, including household economic characteristics (Pachauri 2004, Druckman and Jackson 2008, Cayla et al. 2011, Brounen et al. 2012, O'Neill and Chen 2002, Santin 2011, Rahut et al. 2016), household sociodemographic factors (Kaza 2010, Miah et al. 2011, Rahut et al. 2014, Jones et al. 2015, Kelly 2011, Brounen et al. 2012, Kaza 2010, O'Neill and Chen 2002, Özcan et al. 2013), physical characteristics of the house or construction quality (Daioglou et al. 2012, Kavousian et al. 2013, Valenzuela et al. 2014), home appliances (Stiri 2014, Huang 2015), residential location (Feng et al. 2011, Druckman and Jackson 2008, Daioglou et al. 2012), local climate factors (Kavousian et al. 2013, Valenzuela et al. 2014), and energy costs (Larsen and Nesbakken 2004, Kasparian 2009, Niu et al. 2016). However, the number of studies considering housing type and/or local degree of urbanization (rural-urban) as additional drivers of energy consumption has not been extensive (Wiesmann et al. 2011, Heinonen and Junnila 2014, Stiri 2014, Huang 2015).

For example, Wiesmann et al (2011) estimated electricity consumption at the municipality level for 2001 and at household level by using the Portuguese consumer expenditure survey that was collected in 2005 and 2006. They used socioeconomic and demographic household characteristics, but also housing characteristics as explanatories variables. Regarding the seconds ones, they used dwelling type (detached house, semidetached house, small apartment building and large apartment building) and the level of urbanization (rural, half-urban and urban). The Ordinary Least Squares estimations at both levels were consistent and indicate that an apartment in a building consumed less than detached house, but also urban households consumes more electricity than rural households.

Heinonen and Junnila (2014) studied Finland residential energy consumption patterns in different housing types (apartment buildings, row-terraced houses and detached houses) and degrees of urbanization (cities, semi-urban areas and rural areas). They found significant behavioural differences between different housing types and rural-urban modes. In fact, they found lower energy use in apartment buildings compared to detached houses and less intensive energy consumption for all types of houses in rural areas. In this study, Heinonen and Junnila (2014) holistically analysed the residential energy consumption in different building types by using the Household Budget Survey for 2006. Thus, they explicitly observed the residential energy consumption patterns of 3984 households and compared explicitly by building type, but no econometric model was estimated, thus it was not possible to generalize the results.

Stiri (2014) analysed the impact of household characteristics and building physical attributes (housing type and size) on residential energy consumption in the USA. He used information provided by the Residential Energy Consumption Survey (RECS) for 11,590 households in 2009. The categories of housing type considered were single family detached, single family attached apartments with 2–4 units and apartments with more than 5 units. By using a structural equation model he demonstrated that the impact of housing type on energy consumption is higher than the corresponding direct impact from household characteristics.

Huang (2015) employed a quantile regression to analyse the determinants of household electricity consumption in Taiwan over the period 1981-2011. The information was provided by Taiwan's Family Income and Expenditure Survey, where 15,000 households were sampled each year. In regard to housing type, Huang (2015) found that larger housing areas and multi-floor houses contributed to higher household electricity consumption and that urban households showed higher electricity use than did rural households.

In general, existing empirical studies seem to agree that energy consumption is lower for apartment buildings than for detached houses; however, the results related to rural versus urban are ambiguous: some of them conclude that energy use seems to be lower in rural areas than in urban areas (Poumanyvong and Kaneko 2010, Niu et al. 2012, Heinonen and Junnila 2014, Huang 2015) and others find the opposite (Norman et al. 2006, Rickwood et al. 2008). However, many of the concrete findings are country specific, and the results also rely on the model, the studied energy type, the studied period, the considered explained variables or the used econometric tool.

This paper analyses household electricity consumption for 2014 in Spain. For the Spanish case, to our best knowledge, only Labandeira et al. (2006, 2012), Blázquez et al. (2013) and Romero-Jordán et al. (2014, 2016) have analysed household electricity demand by using as its determinants not only household socioeconomic and demographic characteristics and climate factors but also some variable related to the location of the house.

Labandeira *et al.* (2006) estimated, for the first time in Spain, a residential energy demand system using 51,691 household annual microdata for the period 1975–1995, by applying an extension of the Almost Ideal Demand Model (Deaton and Muellbauer, 1980). They also estimated the model by considering types of municipalities (rural, village, city). Labandeira *et al.* (2012) estimated the demand model using monthly data for the period 2005-2007 with information from 422,696 households, by applying a panel random effects model. They performed estimations for different regions of the country. Blázquez *et al.* (2012), by using aggregate panel data at the province level for 47 Spanish provinces, estimated a log–log demand equation for electricity consumption using a dynamic partial adjustment for the period from 2000 to 2008. Romero-Jordán *et al.* (2014) analysed the determinants of household electricity demand with a panel data partial adjustment model of the Spanish regions between 1998 and 2009. Furthermore, Romero-Jordán *et al.* (2016) estimated these determinants by applying a quantile regression method using data from 2006–2012. As explanatory variables related to housing location, they used the region and the type of municipality (rural or urban) where housing is sited.

As shown, the abovementioned literature has considered in some way the location of households in Spain as electricity consumption determinants, but the urban sprawl determinant has not yet been specifically considered. This paper focuses on the impact of urban sprawl on Spanish household electricity consumption in 2014. Apart from the impact of household socioeconomic characteristics and physical characteristics of the dwelling, we also studied the urban environment and housing type (detached independent house or part of a building). Finally, as prior studies (Kaza 2010, Valenzuela et al. 2014, Huang 2015, Niu et al. 2016, and Romero-Jordán et al. 2016 for the Spanish case) suggested that explanatory variables may exhibit variation in magnitude and sign depending on household energy use quantile, the empirical study is extended by estimating a quantile regression model. The obtained information could be very useful for designing specific energy efficiency measures on groups with higher electricity consumption.

3. The Spanish case: dataset and selected variables

The data used in this analysis are obtained from the Household Budget Survey (HBS) of the National Statistical Institute (INE), a survey that provides information about the patterns of consumption, income and other socioeconomic and demographic characteristics of Spanish households. The dataset is formed from 21,790 observations that are disaggregated across the 17 regions at the NUTS-II level. This survey is obtained yearly since 2006. In this paper, the most recently available information of 2014 is used.

The HBS is composed of three data files: (i) the Household file, which provides information about the Autonomous Community that the household belongs to, the city size, the population density, the income level, number of members, number of employees, some characteristics about the household head such as age, sex, education level, marital status, among others, and some information about the characteristics of the house, such as the size in m^2, the construction year or, among others, if it is a detached house, a semidetached house or an apartment in a residential building; (ii) the Expenditure file, which represents all households with any expenditure; and, (iii) the Household members file, which contains all the information about each member in the household.

As an explicative variable of our analysis, we use the electricity consumption in terms of kW (*LELECTRICITYQ,* in logarithm). In accordance with the literature quoted in the previous section, we use a standard set of variables to explain this electricity consumption assuming the limitations of the database. The set of selected variables is summarized in Table 1.

A particularly relevant variable in any consumption analysis is the price of the product. The HBS give us an especially precise way of obtaining the real final price that the families are facing for their electricity consumption. Households not only report their expenditures for each good but also the physical amount they bought. Therefore, individual prices at which households purchase the electricity can be recovered by dividing monetary expenditures on it by physical quantities (kW) consumed. In accordance with the demand system literature (Deaton, 1988), we refer to these "prices" as *unit values*. The empirical experience demonstrated that *unit values* are very useful as an indicator of time and spatial price variations. The *LELECTRICITYP* variable is the logarithm of this unit value obtained for each household.

Although all households in Spain need to use electricity for certain purposes, in some buildings, it is possible to use other energy sources such as gas, petrol or coal for heating or hot water. The database gives us information to propose proxies that inform us about the consumption of these other energy sources. Using this information, we define the dummies *HEATING* and *HOTWATER* to take a value 1 if the house only used electricity for all the energy consumption and 0 if the house used other energy sources for heating, in the first case, and hot water, in the second one.

To complete this basic information with socioeconomic or housing observable characteristics we add to the model variables such as *HOUSEAGE*, a dummy that takes a value 1 if the house is older than 25 years and 0 otherwise, *INCOME*, a categorical variable that gives us information about the income level of the head of the family, *FAMILYMEMBERS*, a variable that informs us about the number of members of the family, and *HOUSE*, a dummy variable, that takes a value 1 if the family lives in a detached isolated or semidetached house and 0 if they live in an apartment or flat in a residential building or similar construction.

For the propose of this research we focus special attention on this last variable, *HOUSE*, because it informs us about the relevance of living in a detached isolated house typical in sprawled cities in comparison with the usual type of houses in compacted cities, flats in buildings. We complete this variable with others that provide complementary information about the urban environment. *URBAN* is another dummy that takes value 1 when the house is located in a municipality with more than 100,000 inhabitants and 0 otherwise. Although the limit of 100,000 inhabitants is not the most proper to delimit an agglomeration in the particular case of the Spanish urban system, this boundary is able to delimit quite precisely the larger municipalities and main cities of the country (see Polèse et al., 2009). We also include spatial variables that allow us to measure the regional and local effect. In particular, we add a dummy variable of the regional zone (NUTS2 level of desegregation) in which the house is located (variable *REGION*).

>>> INSERT ARROUND HERE TABLE 1 <<<

4. Estimation strategy: a two-stage estimation method and quantile regression

Based on the above information, the basic empirical model that we propose can be written as

$$ELECTRICITYQ = \beta_0 + \beta_1 HOUSE + \beta_2 URBAN + \beta_x X + u \qquad [1]$$

where *LELECTRICITYQ* is our dependent variable, *HOUSE* and *URBAN* are the variables that we focus our analysis on to observe the relevance of urban size and type of house, and X is a vector of all control variables normally considered in the literature: *LELECTRICITYP, HOTWATER, HEATING, INCOME, OWNERSHIP, HOUSEAGE* and *REGION*. Finally u is the random error term of the estimation.

It should be noted that housing socioeconomic characteristics could influence not only household electricity consumption (Rahut et al. 2016) but also housing type choice. For example, having a large family size or a high income could increase the likelihood of living in a detached house (Beguin, 1982; Boehm, 1982). Therefore, an endogeneity problem can emerge if the decision to live in a detached house is partially affected by the anticipated energy consumption, as well as by the other repressors included in the model, making the OLS estimator inconsistent. To address this problem, the dummy of detached is instrumented by defining a variable, observable in the HBS, associated with detached but not correlated with the energy consumption.

Using this instrumental variable, we propose a two-stage estimation method (2SLS). The decision to live in a detached house or not is instrumented by using two additional exogenous variables:

- *RURAL:* which indicates if the house is situated in a rural area. It should be remarked that this "rural" classification is related to the environment, not the population. The HBS classifies the households situated in industrial rural settings, agricultural rural settings and fishing rural settings; conversely, there are households located in different urban settings such as luxury urban, semi-luxury and poor urban settings. With all this information a dummy variable is constructed and takes the value 1 if the households are located in a rural setting and 0 otherwise.
- *LFUELEXP:* a continuous variable defined as the logarithm of the expenditure in Euros of fuel used for transport motors such as cars. This is clearly related to the type of house, a detached isolated house normally implies higher expenditure in fuel but is independent of electricity consumption.

After controlling the endogeneity problem by this procedure an additional issue is that we are interested in observing if the consumption patterns change depending on the distribution of consumption. This is possible using the quantile regressions (QR) approach (Koenker and Basset, 1978), which fits quantiles of consumption of electricity to a linear function of covariates. In its simplest form, the least absolute deviation estimator fits medians to a linear function of covariates. The method of quantile regression is more attractive because medians and quantiles are less sensitive to outliers than means, and therefore ordinary least squares (OLS). Indeed, the likelihood estimator is more efficient than the OLS one. Quantile regressions allow that different solutions at different quantiles may be interpreted as differences in the response of the dependent variable to changes in the regressors; thus, quantile regressions detect asymmetries in the data that cannot be detected by OLS. However, the most important feature is that quantile regression analyses the similarity or dissimilarity of regression coefficients at different points of the dependent variable, which in this case is the electricity consumption; it allows one to consider the possible heterogeneity across the intensity in electricity demand.

The following expression presents the adaptation of equation [1] in terms of QR:

$$LELECTRICITYQ_{\tau} = \beta_{0\tau} + \beta_{1\tau}HOUSE + \beta_{2\tau}URBAN + \beta_{x\tau}X + u \qquad [2]$$

where coefficients $\beta_{i\tau}$ represent the returns to covariates at the τth quantile of the logarithm of electricity consumption.

QR estimates can be affected by the same endogeneity problems discussed for the case of OLS. This issue is addressed by applying the instrumental variable quantile regression (IVQR) estimator developed by Chernozhukov and Hansen (2005, 2006). The IVQR estimation is based on the same instrument, the variable RURAL, as the 2SLS estimation.

The model is estimated by using the least-absolute value minimization technique and bootstrap estimates of the asymptotic variances of the quantile coefficients are calculated with 20 repetitions.

5. Main results

The final results of all these estimation strategies are summarized in Table 2. The first column of the table presents the results of the 2SLS procedure. The following columns show the coefficients and their significance under the different quantiles 10, 25, 50, 75 and 90, using IVQR. Basic tests, R^2 and χ^2 score for over identifying restrictions are presented at the end of the table.

First, we are going to discuss briefly the control variable results to focus our attention. Second, we will focus on the urban context conclusions.

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5.1. Socioeconomic characteristics

In general, all the socioeconomic and household and housing characteristics are significant and similar to what we can expect according to previous literature.

The price of electricity has the expected negative and significant effect. The value of the coefficient is close to 1 and is stable across the quantile distribution. This indicates that the electricity demand in Spain, according to our results, is unitary. This result is slightly higher than that obtained by Labandeira et al. (2006) and Labandeira et al. (2012) and clearly higher than that obtained by Blazquez et al. (2013). Nevertheless, the result is in line with what was obtained in international studies of electricity demand (see the summary of international results made in Labandeira et al. 2012).

As expected, the houses that combine gas, petrol or coal for heating and hot water, with electricity for the remainder, reduce in a very significant way the final consumption of electricity. This effect is higher for the higher quantiles, indicating that the higher the demand, the larger the effect of using other energy sources. Our result is consistent with most of the previous literature for the Spanish case. Blázquez et al. (2013) used a gas penetration rate (percentage of households that have access to gas) as an explanatory variable and found a significant and negative sign; Moreover, Romero-Jordán et al (2014, 2016) found that a greater penetration of electric heating and electric water heating had a clear positive impact on Spanish electricity consumption. Those studies indicated a clear competition between electricity and gas in the provision of heating and hot water systems in Spanish households. Moreover, the impact of this variable increases when quantile increases as Romero-Jordán et al (2016) also found.

Regarding the age of the house, we find it is significant and positive, indicating that older houses consume more electricity. However, this effect is not significant for the higher quantiles of the distribution.

The number of members in the family is also clearly significant and positive with the expected result that the larger the family is the higher the electricity consumption. This result was also found by Blázquez et al. (2013) and Romero-Jordán et al (2016) in the quantile regression- they also found this result was stable among the quantiles as we find. Contrary Romero-Jordán et al (2014) found household size not significant.

Our results indicate that to be an owner of the house significantly increases electricity consumption, and similar results were found by Labandeira et al. (2006) for Spain.

The demand for electricity is responsive to the level of income with elasticity clearly below 1. This result is stable for the different income levels and for the different quantiles in the quantile estimation. This means that income growth apparently results in a less than proportional increase in electricity demand, implying that a possible convergence in the per capita income of Spain with that of the most advanced countries in the EU-15 will not translate into proportional increases in electrical equipment, and in turn into proportional increases in electricity consumption.

Regional dummies are not stable across the distribution and show different effects. The clearest effect is for the Canary Islands dummy, which reflects the higher final real prices of the electricity due to the isolated situation of this archipelago. In the remaining cases, the effects change between quantiles, preventing clear conclusions. Previous papers obtained similar results indicating that households located in areas with Mediterranean climate (Regions South and East) tend to consume more electricity on average than their counterparts in other parts of the country (Jordán et al 2016).

5.2. Urban context: sprawl and agglomeration effects

Our interest is mainly focused on analysis of the type of house and the size of the urban area, what we call the urban context.

The estimations indicate that a household living in an urban area (municipalities with more than 100,000 inhabitants) significantly decreases electricity consumption compared to those living in a small city or in a rural area. Our results for the quantile regression are the same for all quantiles of the distribution with the exception of the higher electricity consumers, those sited in quantile 90, as for them the variable is not significant

Previous literature about variables similar to this one is inconclusive. Romero-Jordán et al. (2016) found that households in lower quantiles (1-30 quantiles) of the electricity consumption distribution consumed more in urban areas than in rural areas. However, for the remaining households, the consumption increasesed if they were situated in rural areas. In contrast, Labandeira et al. (2006) concluded that rural and village households (those living in municipalities with fewer than 10,001 inhabitants and with more than 10,000 inhabitants but fewer than 50,001, respectively) spent more on electricity that households living in an urban municipality (municipalities with more than 50,000 inhabitants) for the period 1973 to 1995. However, once they accounted for both direct and indirect effects through an interaction term between total household expenditure and type of municipality, they found that rural households spent more on electricity.

There are several possible explanations for our result. First, it could be due to building construction practices in high density urban areas resulting in a larger proportion of apartment buildings with comparatively less heating and cooling requirements than detached or semidetached houses (which consume more electricity as we have shown). Second, urban environments change the life patterns such that more time is spent away from home, more often having lunch and dinner outside, consuming more intensively external services for taking care of children or dependent members of the family, and more frequently pursuing leisure activities.

Finally, the variable in which we focus special attention is the type of house. Basically, this variable informs us about the impact of living in an isolated house, instead of a flats building, on the energy consumption. What we can observe is that detached or semidetached houses consume significantly more electricity than flats, apartments and other bounding solutions. The effect is significantly relevant, even after controlling for all the socioeconomic variables and after solving a possible endogeneity problem. Our results are similar to those studies analysing the impact of the type of housing on household electricity consumption as it was showed in the above literature review-section 2 (Heinonen and Junnila 2014, Stiri 2014, Huang 2015, Wiesmann et al 2011).

It is also very interesting observing what occurs across the quantiles distribution because this effect is not significant in those houses with lower energy-intensity, but it is higher for the higher quantiles of electricity consumption. Supposedly the households with lower income and less energy purchase capacity are in the low part of the distribution and those that can afford higher demand are in the higher part of the distribution. Thus, this result implies that the effect of sprawl is especially relevant for high-income families.

5. Conclusions and policy implications

This paper estimated the impact of urban sprawl and municipality type on Spanish household electricity consumption. Moreover, household socioeconomic and demographic characteristics are also analysed as determinants of electricity consumption. By using 2014 Household Budged Survey microdata with OLS, as well as a quantile regression econometric approach, our results confirm behaviour of Spanish families similar to the standards in other advanced economies analysed in previous literature.

One of the factors that contribute more to higher electricity demand is the number of members in the family, but the size of Spanish families is supposed to be stable in the future. A unitary electricity-price indicates that households seem to be reactive to energy prices; thus, we can be optimistic about the effectiveness of pricing policies to reduce electricity consumption in Spanish households. At the same time, the low income-elasticity observed indicate that we cannot expect large increases in electricity demand even in the possible context of income growth in the near future.

On the other hand, older houses consume more electricity. New constructions and materials are much more efficient in terms of energy consumption. They are also always prepared to use solar energy. The use of other energy sources for heating and hot water, such as gas, can clearly help in reducing electricity consumption. The problem is that the accessibility and penetration of the gas supply is restricted to some areas connected with the national gas network. These areas are mainly cities with higher density, so the accessibility to gas is going to be reduced for sprawled houses located far from the centre of the city.

We include in our electricity consumption model two variables to evaluate the effect of urban agglomerations and sprawl behaviour. We identify that living in an urban area with more than 100,000 inhabitants, which corresponds to the main cities in Spain, has a significant effect on reducing the electricity demand. Simultaneously, we found that detached and semidetached houses, typical in sprawled landscapes, clearly consume more electricity.

The new trends and housing demands of Spanish families show an increase in sprawl. For different reasons, the number of cities that suffer high levels of sprawl is growing and the proportion of families that choose to live in detached houses is increasing significantly. Detached and sprawled houses mean more consumption of petrol for mobility and reduce the possibility of gas penetration because the infrastructure in a low-density context is much more expensive. What we would like to test in this paper is if it also increases the electricity demand. We include several urban/rural variables, as well as a specific dummy variable, to test if, after controlling for all the socioeconomic and housing characteristics, we can observe a significant positive effect of living in a detached house. Our results clearly confirm this hypothesis. Thus, increasing energy efficiency in detached houses is essential for making progress towards a sustainable city.

In that sense, the *Spanish Energy Saving and Efficiency Action Plan 2011-2020* elaborated by the Ministry of Industry, Tourism and Commerce, and Institute for Energy Diversification and Saving- IDEA (Spanish Government 2011), includes recommendations on energy saving measures in the Building sector, in accordance with the contents of Directive 2010/31/EU related to energy efficiency in buildings (European Commission, 2010) and the Resource Efficient Europe strategy (European Commission, 2011). The measures included in this Action Plan 2011-2020 will involve savings of final energy for 2020 worth 2,867 ktoe in the Building sector. In the residential building sector, savings are derived from energy rehabilitation of the thermal envelope in building stock, renewal of boilers and air conditioning equipment, improvements in the energy efficiency of thermal installations and indoor lighting installations in existing buildings, and also from construction of nearly-zero energy buildings and the rehabilitation of existing ones with high energy qualification (of 8.2 million m^2/year). A summary of other policies adopted by different countries to reduce energy consumption in buildings can be found in Allouhi et al. (2015).

Another strategy to achieve a more sustainable city is the introduction of small installations of renewable thermal energy and cogeneration in household electricity consumption. In that sense, the Spanish Government (2014) approved the Law 413/2014, which establishes, for the first time in Spain, the conditions of auto-consumption of electrical energy power from renewable energy.

As shown, the quantile regression indicated that electricity consumption determinants varied depending on the household energy use quantile. Thus, smart metering and various consumption-feedback systems (Podgornik et al. 2016, Salo et al. 2016), in combination with personal consultations (Stieß and Dunkleberg 2013, Laakso and Lettenmeier, 2016) are proposed instruments for obtaining more efficient and sustainable household energy consumption according to specific characteristics of each household.

In line with current results, further research on this topic would be desirable. For example, to examine the impact of the degree of urbanization and/or the type of energy used by the household on household carbon dioxide emissions could be very interesting in future research, as other authors have noted (Han et al., 2015, Liu et al., 2011, Wang and Yang, 2014, Li et al., 2015, Ye et al., 2017).

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Table 1

Table 1. Summary of the included variables (HBS, 2014)

Variable name		Description
Dependent variable		
LELECTRICITYQ		Logarithm of household electricity consumption (kW)
Independent variables		
LELECTRICITYP		Logarithm of electricity *unitary values* (household supported price in euros)
Other energy sources	*HOTWATER*	Dummy variable which takes the value 1 if the household uses electricity for hot water and 0 if the household uses other energy sources
	HEATING	Dummy variable which takes the value 1 if the household uses electricity for heating and 0 if the household uses other energy sources
Family charac-teristics	*INCOME*	Categorical variable by income brackets: <500, 501-1000, 1001-1500, 1501-2000, 2001-2500, 2501-3000 and >3000 euros
	OWNERSHIP	Dummy variable which takes the value 1 if the house is in property and 0 otherwise
	FAMILYMEMBERS	Number of members of the family living in the house
House characte ristics	*HOUSEAGE*	Dummy variable which takes the value 1 if the house is older than 25 years and 0 otherwise
	HOUSE	Dummy variable that take value 1 if the family live is a detached or semidetached house and 0 otherwise
URBAN		Dummy variable that take value 1 if the house is located in a municipality with more that 100,000 inhabitants and 0 otherwise
REGION		Categorical variable by NUTSII regions in Spain: Madrid, Center (without Madrid), Northwest, Northeast, East, South and Canary Islands

Table 2

Table 2. 2SLS and IVQR estimates[(a)]

	2SLS	2SLS QR				
		0.10	0.25	0.50	0.75	0.90
Constant	6.0815***	5.2605***	5.6192***	5.9367***	6.3539***	6.7661***
LELECTRICITYP	-1.0792***	-1.08972***	-1.1168***	-1.1606***	-1.1275***	-1.0397***
HOT WATER	0.2082***	0.1493***	0.1819***	0.2099***	0.2269***	0.2839***
HEATING	0.1845***	0.1015***	0.1125***	0.1622***	0.2399***	0.3263***
INCOME<500 (Ref.)	-	-	-	-	-	
INCOME 500-1000	-0.3373***	-0.2365***	-0.2692***	-0.2760***	-0.3330***	-0.3723***
INCOME 1000-1500	-0.2755***	-0.2299***	-0.2393***	-0.2381***	-0.2742***	-0.3306***
INCOME 1500-2000	-0.2344***	-0.1574***	-0.1714***	-0.2191***	-0.2671***	-0.3283***
INCOME 2000-2500	-0.2079***	-0.1556***	-0.1423***	-0.1677***	-0.2550***	-0.2927***
INCOME 2500-3000	-0.1693***	-0.1456***	-0.1606***	-0.1601***	-0.1757***	-0.1989***
INCOME >3000	-0.1818***	-0.2016***	-0.1750***	-0.1474***	-0.1707***	-0.1932***
OWNERSHIP	0.0904***	0.1470***	0.1145***	0.0753***	0.0591**	0.0259
FAMILYMEMBERS	0.1040***	0.1085***	0.1046***	0.1085***	0.1046***	0.0949***
HOUSEAGE	0.0349***	0.0651***	0.0605***	0.0333**	0.0109	0.0044
HOUSE	0.1283***	-0.0015	0.0471	0.1348***	0.1414***	0.2489***
URBAN	-0.0449***	-0.0567**	-0.0580***	-0.0450**	-0.0448**	-0.0225
REGION MADRID (Ref.)	-	-	-	-	-	-
REGION CENTER (without Madrid)	0.0036	0.0957**	0.0246	-0.0186	-0.0044	-.0469
REGION NORTHWEST	-0.0278	0.0697**	-0.0114	-0.0620**	-0.0474*	-0.1094***
REGION NORTHEAST	-0.0259	0.0421	-0.0107	-0.0453**	-0.0531*	-0.0809**
REGION EAST	0.0716***	0.1326***	0.0921***	0.0372	0.0504*	0.0338
REGION SOUTH	0.0828***	0.1293***	0.1289***	-0.0411	0.0426	0.0021
REGION CANARY ISLANDS	-0.2933***	-0.0304	-0.0696	-0.2529**	-0.3943***	-0.6598***
R^2	0.397	-	-	-	-	-
Score χ^2 for overidentifying restrictions[(b)]	1.52266 (0.2172)	-	-	-	-	-

Note: *, ** and *** represent estimates significantly different of zero at 10%, 5% and 1%, respectively.

[(a)] In order to overcome any possible autocorrelation and heteroskedasticity in the error terms in the models we used an Heteroskedasticity and Autocorrelation Consistent estimator to provide a robust estimation of the covariance matrix of the parameters of a regression-type model.

[(b)] Wooldridge's score χ^2 for overidentifying restriction tests whether the instruments are uncorrelated with the error term. The value in parenthesis reports the p-value. The result for our specification is not significant at a 10% level, indicating that we should not reject the null hypothesis that our instruments are valid.