Journal of Cleaner Production xxx (2017) 1–8

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Energy consumption and urban sprawl: Evidence for the Spanish case

Elena Lasarte Navamuel [a], Fernando Rubiera Morollón [b, *], Blanca Moreno Cuartas [b]

[a] University of Extremadura, Spain
[b] Regional Economics Laboratory, University of Oviedo, Spain

ARTICLE INFO

Article history:
Received 14 October 2016
Received in revised form
31 May 2017
Accepted 13 August 2017
Available online xxx

Keywords:
Household energy consumption
House characteristics
Urban sprawl
Urban energy efficiency

ABSTRACT

Residential electricity consumption constitutes one of the largest sources of Spanish final energy demand. To improve electricity savings, policies oriented towards efficiency in residential consumption, such as replacement of appliances or the construction of nearly-zero energy buildings, have been suggested and implemented. However, the potential relevance of urban structural characteristics, such as the increase in detached houses in sprawling residential areas, has not often been considered. The aim of this research is to analyse the relevance of living in a detached house located in a dispersed urban area to household electricity consumption. Thus, an electricity consumption model is estimated by using household socioeconomic variables and including urban characteristics as its determinants, such us the level of urban agglomeration or whether families live in detached-sprawling homes. The model is estimated by using 2014 Household Budget Survey (HBS) microdata and applying Ordinary Least Squares (OLS) as well as quantile regressions (QR) as econometric procedures. Endogeneity problems are corrected by means of instrumental variables. The results confirm that living in a detached house significantly increases electricity consumption, whereas urban agglomerations have the opposite effect. Sprawl is occurring rapidly in Spanish cities, and according to our results, it could constitute a relevant source of increase in electricity demand in the following years.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

The worldwide population is continuously increasing, and it is expected that 85% of the population will live in urban areas after 2010. In a rapidly urbanizing world, how cities are planned, built, operated and redefined has huge social and economic impact. Urban poverty, inequality, 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 various countries draw attention to sustainable urban growth and, particularly, to understanding 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, innovation in cities has relied on the capacity of new technologies to develop “smart cities”, those that are monitored with networks of devices that give precise information on pollution (Lambrechts and Sinha, 2016) and local mobility (Castell et al., 2016), allowing a better understanding of city life and problems. Other lines of current research are in the investigation of the use of new materials (Motuzienė et al., 2016) and building technologies (Morán et al., 2016) to improve housing energy performance. Moreover, the relationship between urban form and greenhouse gas emissions (GHG) from home consumption and private driving has been studied (Wilson and Chakraborty, 2013 summarized empirical studies of the environmental impacts). For example, Wiedenhofer et al. (2013) focused on the GHG emissions from energy requirements of household consumption and VandeWeghe and Kennedy (2007) from transport and building operations. Ottelin et al. (2015), Ala-Mantila et al. (2013) and Heinonen et al. (2013) analysed the GHG emissions from total household consumption. Other studies have focused on the effect of urban sprawl on household energy consumption (Stiri, 2014; Wiesmann et al., 2011; Heinonen and Junnila, 2014; or Huang, 2015 for Taiwan, among others).

However, despite the number of studies analysing the effect of urban sprawl on energy consumption, there is still room for new studies as those effects rely on the measures of urban sprawl, the time period and country considered or the econometric technique

* Corresponding author.
E-mail address: frubiera@uniovi.es (F. Rubiera Morollón).

http://dx.doi.org/10.1016/j.jclepro.2017.08.110
0959-6526/© 2017 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Navamuel, E.L., et al., Energy consumption and urban sprawl: Evidence for the Spanish case, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.08.110

used in the analysis.

The phenomenon of urban sprawl has been analysed 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. It is also connected with other fundamental topics and concepts in urban planning and urban economics literature, such as urban metabolism (for a review of this concept see Kennedy et al., 2011). 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 sprawling 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 are, the higher the degree of urban sprawl is. 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. From the energy consumption perspective, the effect of sprawl can be identified by the effect of living in detached houses in low-building-density areas.

According to Gillham (2002), the Central and Western United States are considered to contain some of the first cities that began to experience urban sprawl; however, the phenomenon rapidly extended first to Latin America (see Gilbert, 1996; Polèse and Champain, 2003) and later to Asian cities (see Bunnel et al., 2002), finally becoming global. 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 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 second residences. The Spanish economy has been drastically affected by the construction sector suffering one of the largest real estate bubbles of all of Europe (Romero, 2012). Spain had very rapid 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 populations in less than twenty years. Other major metropolitan areas in the country experienced such growth that different cities or towns grew into one. Rural areas also lost most of their populations in just two decades. Additionally, the tourism sector explosion during the last decades intensely affected many Spanish cities, which suffered processes of tourism urban metabolism, similar to those analysed in Zorpas et al. (2017). The strong changes in income per capita, social customs and land use pressures have made Spain a victim of urban sprawl (Rubiera et al., 2016).

The specific interest of this research is to measure and evaluate the effect of living in a detached house, the typical type of house in sprawling cities, on residential electricity consumption in the case of Spain. The Household Budget Survey (HBS) elaborated by the National Institute of Statistics (INE) provides information about energy consumption as well as family and house characteristics. With this database, we can estimate a model of household electricity consumption and evaluate, among other variables, the relevance of the specific characteristics of the house, including the particular impact of being a detached house in a sprawling residential area.

Residential energy consumption constitutes one of the largest sources of Spanish final energy demand—19% in 2014, according to the European Commission (2016). Consequently, this research focuses 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 Goverment, 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 household energy consumption. In contrast, the number of works focused on analysing the urban structure characteristics or, in particular, the growing phenomenon of building dispersion or urban sprawl over household electricity consumption in Spain is much lower.

According to INE (2012), 35% of Spain's population live in houses, with 11% living in detached houses and 24.2% in semi-detached houses. The remaining percentage of the population is distributed among other types of houses, such as flats. What is proposed 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 these factors affect energy consumption. The obtained results could guide state and local governments in developing energy-efficient strategies for urban planning. A more electricity-efficient urban design cannot only decrease the energy dependency of the Spanish economy and achieve energy savings but also improve the environment by reducing GHG emissions and help fulfil the EU's 2020 and 2030 climate and energy goals (Council of the European Union, 2010; 2014).

2. Material and methods

2.1. Variable discussion for an empirical model of electricity consumption with housing characteristics

As explained in the previous section, the objective of this research is to measure and evaluate the effect of living in a detached house on electricity consumption in Spain. To do so, the first step should be to define an empirical model of household electricity consumption supported by previous empirical and theoretical literature.

As is obvious in the analysis of household energy consumption, there are expectable factors that should be considered, such as energy costs (Larsen and Nesbakken, 2004; Kasparian, 2009; Niu et al., 2016), 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) and 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). However, another set of variables, such as physical characteristics of the house or construction quality (Daioglou et al., 2012; Kavousian et al., 2013; Valenzuela et al., 2014), the characteristics of home appliances (Stiri, 2014; Huang, 2015), residential location (Feng et al., 2011; Druckman and Jackson, 2008; Daioglou et al., 2012), and local climate factors (Kavousian et al., 2013;

Please cite this article in press as: Navamuel, E.L., et al., Energy consumption and urban sprawl: Evidence for the Spanish case, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.08.110

Valenzuela et al., 2014) should also be included.

Moreover, some studies have considered housing type and/or local degree of urbanization (rural-urban) as additional drivers of energy consumption (Wiesmann et al., 2011; Heinonen and Junnila, 2014; Stiri, 2014; Huang, 2015).

For example, Wiesmann et al. (2011) estimated electricity consumption at the municipal level in 2001 and at the 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 explanatory variables. Regarding the latter, they used dwelling type (detached house, semidetached house, small apartment building and large apartment building) and 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 a detached house but also that urban households consume more electricity than rural households.

Heinonen and Junnila (2014) studied Finland's 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 them explicitly by building type; however, no econometric model was estimated. Thus, it was not possible to generalize the results.

Stiri (2014) analysed the impact of household characteristics and physical building 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 of 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, in which 15,000 households are surveyed each year. With regard to housing type, Huang (2015) found that larger houses 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 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, studied energy type, studied period, considered explained variables and/or used econometric tool.

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 and type of municipality (rural or urban; rural, village or city) or region where the housing is located.

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 type of municipality (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. (2013), 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 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 to 2012. As explanatory variables related to housing location, they used the region and the type of municipality (rural or urban) where the housing was located.

As shown, for the Spanish case, the above studies did not include any variable related to housing type related to urban sprawl (e.g., semi-detached, detached). Our study seeks to close this gap, measuring and evaluating the effect of living in a detached house—the typical type of house of sprawling cities—on household electricity consumption in Spain.

2.2. Database for the Spanish case analysis: the HBS

The data used in this analysis are obtained from the HBS (INE, 2016), a survey that provides information about patterns of consumption, income and other socioeconomic and demographic characteristics of Spanish households. The dataset is disaggregated across the 17 regions at the NUTS2 level. This survey is obtained yearly since 2006. In this paper, the most recently available information from 2014 is used.

The HBS is composed of three data files: (i) the Household file, which provides information about the Autonomous Community to which the household belongs; the city size; the population density; the income level; the number of members; the number of employees; some characteristics about the household head, such as age, sex, education level, and marital status; 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 the members of the household.

In the HBS, among all the expenditures of the families, data file (ii), information about electricity consumption is provided in kilowatts per hour (kWh) and in Euros. For this analysis, the kWh consumption per household is used as the explicative variable. *LELECTRICITYQ*, the dependent variable, is the logarithm of the kWh of electricity consumed by each household in the survey. Table 1 presents a basic statistical description of the dependent variable and information about its spatial distribution.

In accordance with the literature quoted in the previous section, a standard set of variables to explain this electricity consumption

Please cite this article in press as: Navamuel, E.L., et al., Energy consumption and urban sprawl: Evidence for the Spanish case, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.08.110

Table 1
Descriptive statistics of household electricity consumption in kWh (INE, 2014).

Percentiles	Household electricity consumption in kWh				
	Total	Urban areas[a]	Rural areas[a]	Detached houses	Building Apartments
5%	1019.4	1023.6	996	1135.8	973.8
10%	1317.6	1308	1347.6	1470	1248
25%	1869.6	1855.8	1944	2136.6	1762.2
50%	2627.4	2599.5	2740.8	3012	2442
75%	3662.4	3624	3860.4	4222.2	3348
90%	5088	5020.8	5358	5940	4500
95%	6408	6252	6810	7524	5550
Mean	**3053.37**	**3009.74**	**3242.31**	**3539.6**	**2766.4**
Obs	11,583	9410	2173	4299	7284

[a] The delimitation among urban and rural areas is provided by HBS according with the land classification.

assuming the limitations of the database are also considered. The set of selected variables is summarized in Table 2.

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 families face for their electricity consumption. Households report not only their expenditure for each good but also the physical amount they buy. Therefore, the individual prices at which households purchase electricity can be determined by dividing the monetary expenditures in the HBS by the physical quantities (kWh) consumed. In accordance with the demand system literature (Deaton, 1988), we refer to these "prices" as *unit values*. The empirical experience demonstrates 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 must 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, the dummies *HEATING* and *HOTWATER* are defined to take the value 1 if the house only used electricity for all its energy consumption and 0 if the house used other energy sources for heating, in the first case, and hot water, in the second.

To complete this basic information with observable socioeconomic or housing characteristics, variables are added. They are *HOUSEAGE*, a dummy that takes the 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 size of the family in terms of its number of members and *HOUSE*, a dummy variable that takes the 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 purposes of this research, spatial attention is turned towards this last variable, *HOUSE*, because it informs us about the relevance of living in a detached isolated house typical in sprawling cities in comparison with the usual type of houses in compact cities—flats in buildings. This variable is complemented with others that provide additional information about the urban environment. *URBAN* is another dummy that takes the 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 appropriate 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. 2007). Spatial variables that allow us to measure the regional and local effects are also included. In particular, a dummy variable of the regional zone (NUTS2 level of desegregation) in which the house is located (variable *REGION*) is added.

2.3. Model and econometric strategy

Based on the above information, the basic empirical model proposed can be written as:

$$ELECTRICITYQ = \beta_0 + \beta_1 HOUSE + \beta_2 URBAN + \beta_x X + u \quad (1)$$

where *LELECTRICITYQ* is our dependent variable, *HOUSE* and *URBAN* are the variables on which the analysis is focused to determine the relevance of urban size and type of house, and *X* is a vector of all the control variables normally considered in the literature (variables in

Table 2
Summary of the included variables (INE, 2014).

Variable name		Description
Dependent variable		
LELECTRICITYQ		Logarithm of household electricity consumption in kilowatts per hour (kWh) (Table 1)
Independent variables		
LELECTRICITYP		Logarithm of electricity *unitary values* (household supported price in Euros)
Other energy sources	*HOTWATER*	Dummy variable that takes the value 1 if the household uses electricity for hot water and 0 if the household uses other energy sources
	HEATING	Dummy variable that takes the value 1 if the household uses electricity for heating and 0 if the household uses other energy sources
Family characteristics	*INCOME*	Categorical variable by income bracket: <500, 501-1,000, 1001-1,500, 1501-2,000, 2001-2,500, 2501-3000 and > 3000 Euros
	OWNERSHIP	Dummy variable that takes the value 1 if the house is owned by the tenant and 0 otherwise
	FAMILYMEMBERS	Size of the family in terms of the number of members of the family living in the house
House characteristics	*HOUSEAGE*	Dummy variable that takes the value 1 if the house is older than 25 years and 0 otherwise
	HOUSE	Dummy variable that takes the value 1 if the family lives in a detached or semidetached house and 0 otherwise
Urban		Dummy variable that takes the value 1 if the house is located in a municipality with more than 100,000 inhabitants and 0 otherwise
Region		Categorical variable by NUTS2 regions in Spain: Madrid, Centre (without Madrid), Northwest, Northeast, East, South and Canary Islands

Please cite this article in press as: Navamuel, E.L., et al., Energy consumption and urban sprawl: Evidence for the Spanish case, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.08.110

Table 1). 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 regressors 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 housing but not correlated with the energy consumption.

Using this instrumental variable, a two-stage estimation method (2SLS) is proposed. The decision whether to live in a detached house is instrumented by using two additional exogenous variables:

- *RURAL:* indicates whether the house is situated in a rural area. It should be noted that this "rural" classification is related to the environment, not the population. The HBS classifies 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 household is 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 means of transport, 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 to observe whether the consumption patterns change along with the distribution. As prior studies (Kaza, 2010; Valenzuela et al., 2014; Huang, 2015; Niu et al., 2016; Romero-Jordán et al., 2016 for the Spanish case) suggested that explanatory variables may exhibit variation in magnitude and sign depending on the household energy use quantile, the empirical study is extended by estimating a quantile regression model. This is possible using the quantile regressions (QR) approach (Koenker and Basset, 1978), which fits quantiles of electricity consumption 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 different solutions at different quantiles to 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.

3. Results and discussion

The final results of all these estimation strategies are summarized in Table 3. 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 overidentifying restrictions are presented at the end of the table.

First, the control variable results are discussed briefly; next, the urban context conclusions are presented.

3.1. Socioeconomic characteristics

In general, all the socioeconomic, household and housing characteristics are significant and similar to what is expectable 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, 2012) and clearly higher than that obtained by Blázquez et al. (2013). Nevertheless, the result is in line with those obtained in international studies of electricity demand (see the summary of international results made in Labandeira et al., 2012).

As expected, houses that combine gas, petrol and/or coal for heating and hot water, with electricity for the remainder, dramatically reduce the final consumption of electricity. The obtained results indicate that Spanish households use electricity for space heating and domestic hot water heating, as electricity consumption increases an average of 20.82% for hot water and 18.45% for heating. This effect is greater for the higher quantiles, indicating that the higher the demand is, the larger the effect of using other energy sources is.

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 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.

To extract environmental conclusions from these results, it is necessary to know which alternative sources are more sustainable than electricity, also depending on how the electricity is produced. The use of gas, petrol or coal resources has a similar or even higher impact on CO_2 emissions than the use of electricity. An alternative to generate electricity savings for heating but also reducing primary energy consumption (such as gas or petrol) is micro-cogeneration or residential cogeneration. Micro-cogeneration is a combined heat and power system for homes that allows producing electric

Please cite this article in press as: Navamuel, E.L., et al., Energy consumption and urban sprawl: Evidence for the Spanish case, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.08.110

Table 3
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 > 3000 (Ref.)	–	–	–	–	–	
Income 3000-2500	−0.3373***	−0.2365***	−0.2692***	−0.2760***	−0.3330***	−0.3723***
Income 2500-2000	−0.2755***	−0.2299***	−0.2393***	−0.2381***	−0.2742***	−0.3306***
Income 2000-1500	−0.2344***	−0.1574***	−0.1714***	−0.2191***	−0.2671***	−0.3283***
Income 1500-1000	−0.2079***	−0.1556***	−0.1423***	−0.1677***	−0.2550***	−0.2927***
Income 1000-500	−0.1693***	−0.1456***	−0.1606***	−0.1601***	−0.1757***	−0.1989***
Income > 500	−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 centre (without Madrid)	0.0036	0.0957**	0.0246	−0.0186	−0.0044	−0.0469
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 from zero at 10%, 5% and 1%, respectively.

[a] To overcome any possible autocorrelation and heteroskedasticity in the error terms in the models, an Heteroskedasticity and Autocorrelation Consistent estimator is used 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 parentheses reports the p-value. The result for our specification is not significant at a 10% level, indicating that the null hypothesis should not be rejected, which implies that our instruments could be considered valid.

power and heat by small fuel cells or solar energy, among other sources. Micro-cogeneration systems have the potential to reduce energy demands of the residential sector for space heating, domestic hot water heating, and electricity. See, for example, Dorer et al. (2005) for an assessment of fuel cell micro-cogeneration for different types of residential buildings or Pearce (2009) for micro-cogeneration based on solar photovoltaic energy.

Regarding the age of the house, it is found to be 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 is. This result was also found by Blázquez et al. (2013) and Romero-Jordán et al. (2016) in the quantile regression; they also found that this result was stable among the quantiles as found in our results. In contrast, Romero-Jordán et al. (2014) found that household size is not significant.

Our results indicate that owning a house significantly increases electricity consumption, and similar results were found by Labandeira et al. (2006) for Spain. Regarding this issue, since June 2013, property owners are required to obtain energy efficiency certificates before they can sell or rent their homes in Spain (Spanish Goverment, 2013-Real Decreto 235/2013). Gangolells et al. (2016) studied the database for Spanish residential buildings, concluding that "single-family houses use more energy (248.1 kWhp/m^2) than apartments (183.3 kWhp/m^2)", which is in agreement with the results that are obtained in our estimation (see next section).

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 electricity due to the isolated location 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 a Mediterranean climate (Regions South and East) tend to consume more electricity on average than their counterparts in other parts of the country.

3.2. Urban context: sprawl and agglomeration effects

This research is mainly focused on analysis of the type of house and size of the urban area, which is called the urban context.

The estimations indicate that a household in an urban area (a municipality with more than 100,000 inhabitants) consumes significantly less electricity than one living in a small city or a rural area. Our results for the quantile regression are the same for all the quantiles of the distribution with the exception of the higher electricity consumers, those situated 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) of the electricity consumption distribution

consumed more in urban areas than in rural areas. However, for the remaining households, the consumption increased if they were situated in rural areas. In contrast, Labandeira et al. (2006) concluded that rural and village households (those 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 in urban municipalities (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 shown). Second, urban environments change life patterns such that more time is spent away from home, eating lunch and dinner out more often, more intensively consuming external services to care for children or dependent members of the family, and more frequently pursuing leisure activities.

Finally, the variable on which special attention is placed is the type of house. Basically, this variable informs us about the impact of living in an isolated house, instead of an apartment building, on energy consumption. What is observed is that detached or semidetached houses consume significantly more electricity than flats, apartments and other attached housing. 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 of studies analysing the impact of housing type on household electricity consumption as shown in the above literature review in section 2 (Heinonen and Junnila, 2014; Stiri, 2014; Huang, 2015; Wiesmann et al., 2011).

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

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 sprawling 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. However, this paper contributes confirmation that detached houses seem to be less efficient in terms of electricity consumption. Thus, increasing energy efficiency in detached houses is essential for making progress towards sustainable cities.

As shown, the quantile regression indicates that electricity consumption determinants vary 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 (Stieβ and Dunkleberg, 2013; Laakso and Lettenmeier, 2016), are proposed instruments for bringing about more efficient and sustainable household energy consumption according to specific characteristics of each household.

4. Conclusions

The aim of this research is to analyse the relevance of living in a detached house located in a dispersed urban area to household electricity consumption. Thus, an electricity consumption model is estimated by using household socioeconomic variables and including the level of urban agglomeration or whether families live in detached-sprawling houses. The model is estimated by using 2014 HBS microdata and applying OLS and QR as econometric procedures. Endogeneity problems are corrected by means of instrumental variables.

One of the factors that contribute to higher electricity demand is the number of members of the household; however, the size of Spanish families is expected to be stable in the future. A unitary electricity-price indicates that households seem to be reactive to energy prices; thus, it is possible to be optimistic about the effectiveness of pricing policies to reduce electricity consumption in Spanish households. At the same time, the low income-elasticity observed indicates that there are no expectable large increases in electricity demand even in the possible context of income growth in the near future. However, new construction and materials are much more efficient in terms of energy consumption. They are also always equipped to use solar energy. The use of other energy sources for heating and hot water, such as gas, can clearly help reduce electricity consumption.

Two variables to evaluate the effect of urban agglomerations and sprawl behaviour are included in the electricity consumption model. As a result, it is possible to 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, it is found that detached and semidetached houses, typically in sprawling landscapes, clearly consume more electricity.

In line with current results, further research on this topic would be desirable. For example, examining the impact of the degree of urbanization and/or the type of energy used by the household on household carbon dioxide emissions could be 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).

References

Ala-Mantila, S., Heinonen, J., Junnila, S., 2013. The greenhouse gas implications of urban sprawl in Helsinki Metropolitan Area. Sustainability 5, 4461–4478.
Beguin, H., 1982. The effect of urban spatial structure on residential-mobility. Ann. Reg. Sci. 16, 16–35.
Blázquez, L., Boogen, N., Filippini, M., 2013. Residential electricity demand in Spain: new empirical evidence using aggregate data. Energy Econ. 36, 648–657.
Boehm, T.P., 1982. A hierarchical model of housing choice. Urban Stud. 19, 17–31.
Brounen, D., Kok, N., Quigley, J.M., 2012. Residential energy use and conservation: economics and demographics. Eur. Econ. Rev. 36, 931–945.
Bunnel, T., Drummond, L.B.W., Ho, K.C., 2002. Critical Reflections on Cities in Southern Asia. Brill Academic Press, Singapore.
Castell, N., Liu, H.Y., Dauge, F.R., Kobernus, M., Berre, A.J., Noll, J., Gangdal, R., 2016. Supporting sustainable mobility using mobile technologies and personalized environmental information: the citi-sense-MOB approach in Oslo, Norway. In: Advances and New Trends in Environmental and Energy Informatics. Springer International Publishing, pp. 199–218.
Cayla, J.M., Maizi, N., Marchand, C., 2011. The role of income in energy consumption behavior: evidence from French households data. Energy Policy 39, 7874–7883.
Chernozhukov, V., Hansen, C., 2005. An IV model of quantile treatment effects. Econometrica 73, 245–261.
Chernozhukov, V., Hansen, C., 2006. Instrumental quantile regression inference for structural and treatment effect models. J. Econ. 132, 491–525.
Couch, C., Ldontidou, L., Petschel-Held, G., 2007. Urban Sprawl in Europe. Landscapes, Land-use Change & Policy. Blackwell Publishing, Oxford.
Council of the European Union, 2010. Europe 2020 — a Strategy for Smart, Sustainable and Inclusive Growth. COM(2010) 2020 Final, Brussels.
Council of the European Union, 2014. 2030 Framework for Climate and Energy. Available at: www.ec.europa.eu/energy/2030.
Daioglou, V., Van Ruijven, B.J., Van Vuuren, D.P., 2012. Model projections for household energy use in developing countries. Energy 37, 601–615.
Deaton, A.S., Muellbauer, J.N., 1980. An Almost ideal demand system. Am. Econ. Rev. 83, 570–597.
Deaton, A., 1988. Quality, quantity and spatial variation of price. Am. Econ. Rev. 70, 418–430.

Please cite this article in press as: Navamuel, E.L., et al., Energy consumption and urban sprawl: Evidence for the Spanish case, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.08.110

Druckman, A., Jackson, T., 2008. Household energy consumption in the UK: a highly geographically and social-economically disaggregated model. Energy Policy 36, 3177–3192.
Dorer, V., Weber, R., Weber, A., 2005. Performance assessment of fuel cell micro-cogeneration systems for residential buildings. Energy Build. 37, 1132–1146.
European Commission, 2006. Environmental Aspects of Urban Spread in Europe. Joint Research Centre, European Commission, Brussels.
European Commission, 2016. Eurostat Database. Retrieved 26 September 2016. http://ec.europa.eu/eurostat/data/database.
Feng, Z.-H., Zou, L.-L., Wei, Y.-M., 2011. The impact of household consumption on energy use and CO_2 emissions in China. Energy 36, 656–670.
Gangolells, M., Casals, M., Forcada, N., Macarulla, M., Cuerva, E., 2016. Energy mapping of existing building stock in Spain. J. Clean. Prod. 112, 3895–3904.
Gilbert, A., 1996. The Mega-city in Latin America. United Nations University Press, Tokyo.
Gillham, O., 2002. The Limitless City: a Primer on the Urban Sprawl Debate. Island Press, Washington.
Glaeser, E., Kahn, M., 2004. Sprawl and urban growth. In: Henderson, V., Thisse, J.F. (Eds.), Handbook of Regional and Urban Economics, vol. 4, pp. 2481–2527. Amsterdam: North-Holland.
Han, L., Xu, X., Han, L., 2015. Applying quantile regression and Shapley decomposition to analyzing the determinants of household embedded carbon emissions: evidence from urban China. J. Clean. Prod. 103, 219–230.
Heinonen, J., Jalas, M., Juntunen, J., Ala-Mantila, S., Junnila, S., 2013. Situated Lifestyles II: the impacts of urban density, housing type and motorization on the greenhouse gas emissions of the middle income consumers in Finland. Environ. Res. Lett. 8, 035050.
Heinonen, J., Junnila, S., 2014. Residential energy consumption patterns and the overall housing energy requirements of urban and rural households in Finland. Energy Build. 76, 295–303.
Huang, W.-H., 2015. The determinants of household electricity consumption in Taiwan: evidence from quantile regression. Energy 87, 120–133.
INE (Instituto Nacional de Estadística), 2012. Population Census, 2011. Instituto Nacional de Estadística, Madrid.
INE (Instituto Nacional de Estadística), 2016. Household Budget Survey, 2014. Instituto Nacional de Estadística, Madrid.
Jaeger, J.A.G., Schwick, C., 2014. Improving the measurement of urban sprawl: weighted Urban Proliferation (WUP) and its application to Switzerland. Ecol. Indic. 38, 294–308.
Jones, R.V., Fuertes, A., Lomas, K.J., 2015. The socio-economic, dwelling and appliance related factors affecting electricity consumption in domestic buildings. Renew. Sustain. Energy Rev. 43, 901–917.
Kasparian, J., 2009. Contribution of crude oil price to households' budget: the weight of indirect energy use. Energy Policy 37, 111–114.
Kavousian, A., Rajagopal, R., Fischer, M., 2013. Determinants of residential electricity consumption: using smart meter data to examine the effect of climate, building characteristics, appliance stock, and occupants' behavior. Energy 55, 184–194.
Kaza, N., 2010. Understanding the spectrum of residential energy consumption: a quantile regression approach. Energy Policy 38, 6574–6585.
Kelly, S., 2011. Do homes that are more energy efficient consume less energy? A structural equation model of the English residential sector. Energy 36, 5610–5620.
Kennedy, C., Pinceti, S., Bunje, P., 2011. The study of urban metabolism and its applications to urban planning and design. Environ. Pollut. 159 (8/9), 1965–1973.
Koenker, R., Basset Jr., G., 1978. Regression quantiles. Econometrica 46 (1), 33–50.
Laakso, S., Lettenmeier, M., 2016. Household-level transition methodology towards sustainable material footprints. J. Clean. Prod. 132, 184–191.
Labandeira, X., Labeaga, J.M., López-Otero, X., 2012. Estimation of elasticity price of electricity with incomplete information. Energy Econ. 34, 627–633.
Labandeira, X., Labeaga, J.M., Rodríguez, M., 2006. A residential energy demand system for Spain. Energy J. 27, 87–112.
Lambrechts, J., Sinha, S., 2016. Microsensing networks for sustainable cities: pollution as a key driving factor. In: Microsensing Networks for Sustainable Cities. Springer International Publishing, pp. 1–27.
Larsen, B.M., Nesbakken, R., 2004. Household electricity end-use consumption: results from econometric and engineering models. Energy Econ. 26, 179–200.
Liu, L.C., Wu, G., Wang, J.N., Wei, Y.M., 2011. China's carbon emissions from urban and rural households during 1992–2007. J. Clean. Prod. 19, 1754–1762.
Li, Y., Zhao, R., Liu, T., Zhao, J., 2015. Does urbanization lead to more direct and indirect household carbon dioxide emissions? Evidence from China during 1996–2012. J. Clean. Prod. 102, 103–114.
Miah, M.D., Foysal, M.A., Koike, M., Kobayashi, H., 2011. Domestic energy-use pattern by the households: a comparison between rural and semi-urban areas of Noakhali in Bangladesh. Energy Policy 39, 3757–3765.
Morán, A.J., Profaizer, P., Zapater, M.H., Valdavida, M.A., Bribián, I.Z., 2016. Information and Communications Technologies (ICTs) for energy efficiency in buildings: review and analysis of results from EU pilot projects. Energy Build. 127, 128–137.
Motuzienė, V., Rogoža, A., Lapinskienė, V., Vilutienė, T., 2016. Construction solutions for energy efficient single-family house based on its life cycle multi-criteria analysis: a case study. J. Clean. Prod. 112, 532–541.
Niu, S., Jia, Y., Ye, L., Dai, R., Li, N., 2016. Does electricity consumption improve residential living status in less developed regions? An empirical analysis using the quantile regression approach. Energy 95, 550–560.
Niu, S., Zhang, X., Zhao, C., Niu, Y., 2012. Variations in energy consumption and survival status between rural and urban households: a case study of the Western Loess Plateau, China. Energy Policy 49, 515–527.
Norman, J., MacLean, H.L., Kennedy, C.A., 2006. Comparing high and low residential density: life-cycle analysis of energy use and greenhouse gas emissions. J. Urban Plan. Dev. 132, 10–21.
O'Neill, B.C., Chen, B.S., 2002. Demographic determinants of household energy use in the United States. Popul. Dev. Rev. 28, 53–88.
Ottelin, J., Heinonen, J., Junnila, S., 2015. New energy efficient housing has reduced carbon footprints in outer but not in inner urban areas. Environ. Sci. Technol. 49, 9574–9583.
Özcan, K.V., Gülay, E., Üçdoğru, 2013. Economic and demographic determinants of household energy use in Turkey. Energy Policy 60, 550–557.
Pachauri, S., 2004. An analysis of cross-sectional variations in total household energy requirements in India using micro survey data. Energy Policy 32, 1723–1735.
Pearce, J.M., 2009. Expanding photovoltaic penetration with residential distributed generation from hybrid solar photovoltaic and combined heat and power systems. Energy 34, 1947–1954.
Polèse, M., Champain, C., 2003. La evolución de los centros urbanos: La experiencia de América del Norte. World Bank, Washington.
Polèse, M., Rubiera, F., Shearmur, R., 2007. Observing regularities in location patterns: an analysis of the spatial distribution of economic activity in Spain. Eur. Urban & Reg. Stud. 14 (2), 157–180.
Podgornik, A., Sucic, B., Blazic, B., 2016. Effects of customized consumption feedback on energy efficient behaviour in low-income households. J. Clean. Prod. 130, 25–34.
Poumanyvong, P., Kaneko, S., 2010. Does urbanization lead to less energy use and lower CO2 emissions? Across-country analysis. Ecol. Econ. 70, 434–444.
Rahut, D.B., Das, S., De Groote, H., Behera, B., 2014. Determinants of household energy use in Bhutan. Energy 69, 661–672.
Rahut, D.H., Behera, B., Ali, A., 2016. Household energy choice and consumption intensity: empirical evidence from Bhutan. Renew. Sustain. Energy Rev. 53, 993–1009.
Rickwood, P., Glazebrook, G., Searle, G., 2008. Urban structure and energy – a review. Urban Policy Res. 26, 57–81.
Romero, J., 2012. Construcción residencial y gobierno del territorio de España. De la burbuja especulativa a la recesión, causas y consecuencias. Cuad. Geográficos 47, 17–46.
Romero-Jordán, D., del Río, P., Peñasco, C., 2014. Analysing the determinants of household electricity demand in Spain. An econometric study. Int. J. Electr. Power Energy Syst. 63, 950–961.
Romero-Jordán, D., del Río, P., Peñasco, C., 2016. An analysis of the welfare and distributive implications of factors influencing household electricity consumption. Energy Policy 88, 361–370.
Rubiera, F., González, V., Rivero, J.L., 2016. Urban sprawl in Spain: differences among cities and causes. Eur. Plan. Stud. 24, 204–226.
Santin, O.G., 2011. Behavioural patterns and user profiles related to energy consumption for heating. Energy Build. 43, 2662–2672.
Spanish Goverment, 2013. Real Decreto 235/2013, de 5 de abril, por el que se aprueba el procedimiento básico para la certificación de la eficiencia energética de los edificios. Boletín Oficial del Estado, p. 13.
Spanish Goverment, 2016. Libro de la Energía en España 2014. Spanish Ministry of Industry, Energy and Tourism, Madrid (Spain).
Stiri, H., 2014. Building and household X-factors and energy consumption at the residential sector. A structural equation analysis of the effects of household and building characteristics on the annual energy consumption of US residential buildings. Energy Econ. 43, 178–184.
Salo, M., Nissinen, A., Lilja, R., Olkanen, E., O'Neill, M., Uotinen, M., 2016. Tailored advice and services to enhance sustainable household consumption in Finland. J. Clean. Prod. 121, 200–207.
Stieß, I., Dunkleberg, E., 2013. Objectives, barriers and occasions for energy efficient refurbishment by private homeowners. J. Clean. Prod. 48, 250–259.
Valenzuela, C., Valencia, A., White, S., Jordan, J.A., Cano, S., Keating, J., et al., 2014. An analysis of monthly household energy consumption among single-family residences in Texas 2010. Energy Policy 69, 263–272.
VandeWeghe, J., Kennedy, C., 2007. A spatial analysis of residential greenhouse gas emissions in the toronto census metropolitan area. J. Ind. Ecol. 11, 133–144.
Wang, Z., Yang, L., 2014. Indirect carbon emissions in household consumption: evidence from the urban and rural area in China. J. Clean. Prod. 78, 94–103.
Wiedenhofer, D., Lenzen, M., Steinberger, J., 2013. Energy requirements of consumption: urban form, climatic and socio-economic factors, rebounds and their policy implications. Energy Policy 63, 696–707.
Wiesmann, D., Lima Azevedo, I., Ferrão, P., Fernández, J.E., 2011. Residential electricity consumption in Portugal: findings from top-down and bottom-up models. Energy Policy 39, 2772–2779.
Wilson, B., Chakraborty, A., 2013. The environmental impacts of sprawl: emergent themes from the past decade of planning research. Sustainability 5, 3302–3327.
Ye, H., Ren, Q., Hu, X., Lin, T., Xu, L., Li, X., Zhang, G., Shi, L., Pan, B., 2017. Low-carbon behavior approaches for reducing direct carbon emissions: household energy use in a coastal city. J. Clean. Prod. 141, 128–136.
Zorpas, A.A., Voukkali, I., Navarro, J., 2017. Tourist area metabolism and its potential to change through a proposed strategic plan in the framework of sustainable development. J. Clean. Prod. http://dx.doi.org/10.1016/j.jclepro.2017.02.119) (in press).

Please cite this article in press as: Navamuel, E.L., et al., Energy consumption and urban sprawl: Evidence for the Spanish case, Journal of Cleaner Production (2017), http://dx.doi.org/10.1016/j.jclepro.2017.08.110