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# 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

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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.



## 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).

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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;

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