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Article

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Determinants of household electricity consumption in Greece: a statistical analysis

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Abstract

Over the last decades, the contemporary way of living, as well as the technology development, has increased the household electricity consumption. The excessive use of electricity has a negative impact on the environment, increasing the carbon footprint and contributing to the climate change. Governments are more and more concerned about the way our societies consume energy and are committed to reduce the greenhouse emissions. As the residential sector contributes significantly to energy use, it is crucial to investigate the socio-economic parameters, dwellings' characteristics, and climate conditions that determine the electricity consumption in households. The data of this study are collected from 1801 dwellings from all regions of Greece and two statistical models are built. Both of them conclude that the most significant determinants influencing the electricity consumption are the number of occupants, the size of the dwelling, the heating type, the heating and cooling hours, and the weather conditions.

Keywords: Electricity, Consumption, Determinants, Socio-economic, Statistical analysis

Introduction

In the last decades due to the increased demand and the improved lifestyle, energy demand in the residential sector has increased rapidly causing the policymakers' concern. The international climate negotiation is an opportunity for decision-makers to promote enhancement of energy efficiency and reduction of greenhouse emissions and set commitments for renewable energy consumption. The recent "2030 Energy Strategy" and the Paris climate conference (COP21) focus on the previous objectives to keep a global temperature rise this century below 2 °C. According to IEA (2020a), based on the most recent data of 2018 in Greece, the CO₂ emissions from fuel combustion only come from electricity and heat producers (46.8%), transport (27.4%), industry (8.1%), other energy industries (8.1%), residential (6.5%), commercial and public services (1.6%), and other (1.6%).

In the last two decades, the Greek governments have given a high priority to the environmental protection; thus, they promoted the Renewable Energy Sources (RES). The main aim concerning the RES is to be able to participate in the electricity consumption for at least 40% by the end of 2020. Specifically, under the European Renewable Energy

Directive 2009/28/EC (European Parliament and Council, 2009) and the Law 3851/2010 (Official Government Gazette, 2018), Greece needs to meet the following targets for RES contribution:

- 20% of the final energy consumption for heating and cooling
- 40% of the final electricity consumption
- 10% of the final energy consumption in transportation

According to the most recent provided data by IEA (2017), Greece has achieved its goal in the sector of heating and cooling (58.90%), but is far from its aim in the other two sectors (22.09% and 1.43%, respectively). However, Greece has made an impressive progress in the electricity sector, thanks to the rapid growth in installed wind and solar parks and the decrease in the total electricity demand.

In 2019, RES and gas are the primary fuels of electricity production in Greece (IEA, 2020b). In particular, the total electricity production is based on RES (35.2%), gas (35.2%), coal (22.2%), and oil (9.2%), while in 2017 the corresponding percentages were the following: RES (25.1%), gas (31%), coal (34%), and oil (10%).

Policymakers must focus on the distribution of the electricity consumption, in order to detect and improve the most inefficient sectors. In 2018, the distribution of electricity consumption per sector has been the following: commercial and public services (36%), residential (33.9%), industry (25.1%), agriculture/foster (4.6%), and transport (0.6%); it must be noted that this is similar in the last ten years (IEA, 2020c).

In the residential sector, the final energy consumption is used to heat the space (57%), for lighting and appliances (20%), for heater heating (12%), for cooking (7%), and for space cooling (4%) (Eurostat, 2018).

Consumption per capita is an important indicator to observe the tendency of electricity consumption through the years, as it offers a clear view of the electricity that every individual consumes. In Greece, in 2014 the per capita electricity consumption was 5062.61 kWh/capita while in 2010 was 5333.44 kWh/capita and in 2008 was 5805.19 kWh/capita (DataBank, 2020). The economic crisis in Greece since 2008–2009 influenced the electricity consumption as in 2013 the average consumption fell to 5029 kWh/capita. Consumption per household is another indicator to monitor the electricity consumption in the residential sector. In 2000, the electricity per household (hh) was 3717 kWh/hh, while in 2010 it was 4023 kWh/hh (World Energy Council, 2016).

The increasing trend of electricity consumption is a reality. Since the residential sector is one of the most demanding sectors regarding electricity consumption, it should be studied. Unfortunately, in Greece, the socio-economic parameters that influence the electricity consumption have never been extensively examined. From the previous studies, that are outlined in the “Literature review” section, the electricity consumption is relevant with demographic data, dwelling characteristics and geographical and climate conditions. This study analyzes the aforementioned parameters in Greece and it is based on real data from 1801 customers of a Greece’s electricity provider. The variables and the methodology that are used in the current analysis are in line with the deep literature review that was conducted by Jones et al. (2015).

This paper is organized as follows: in the “Literature review” section, an overview of the literature review relevant for this study is included. A description of the regression

models and the data sources is given in the “Method” section. In the “Results and discussion” section, the main results are summarized. Finally, the conclusions are presented in the “Conclusions” section.

Literature review

On the international stage, residential electricity consumption is a considerably studied subject. Relevant studies are sequenced with the oldest first and the most recent last.

Studies regarding European countries

Halicioğlu (2007) examines how the energy demand in residential sector in Turkey was influenced from the price and income. The income positively influences the electricity demand and accelerates purchases of electrical goods and services. The price of electricity negatively influences the electricity demand, while the urbanization positively influences the electricity demand, as it provides greater access to electricity.

Gram-Hanssen (2011) points out that the user's practices influence the energy consumption. He examines 8500 detached houses in Denmark and he finds that the income, the size of the house, and the presence of teenagers (13–19 years old) all have a positive effect on electricity consumption.

Wiesmann et al. (2011) examine the relationship between the per capita electricity consumption and dwelling characteristics in Portuguese consumers. They conclude that the income, the appliance ownership, and the floor area have a positive influence on per capita electricity consumption. People who live in single-family houses and/or in urban households consume more electricity than those living in a block of flats and/or rural households. People per household, dwellings per building and more heating degree-days negatively influence the consumption per capita, since in colder regions households consume less electricity per capita than those in more moderate climates.

McLoughlin et al. (2012) examine the influence of dwelling and occupant characteristics on electricity consumption of 3941 Irish dwellings. Dwelling type, number of bedrooms, age of the head of household, and electrical appliances used for water heating and cooking have a positive effect on electricity consumption.

Bedir et al. (2013) point out that in Netherlands the household size, the dwelling type, and the duration of electrical appliances' use (such as dryers and washing machines) have significant effect on the electricity consumption. Also, in the Netherlands, Brounen et al. (2012) analyze data of 300,000 dwellings. The dwelling type affects electricity consumption as the detached and semi-detached houses consume more electricity per capita than row houses or apartments. Houses with children and especially those that have teenagers are found to have a positive effect on per capita electricity consumption. The income has positive influence whereas the number of persons in household has a negative effect on per capita electricity consumption.

Studies regarding non-European countries

Ndiaye and Gabriel (2011) analyze electricity consumption of 62 dwellings of Oshawa (Ontario, Canada). Number of residents, house status, type of fuel used to heat the pool, type of fuel used in the heating system, type of fuel used in the domestic hot water heater, type of air-conditioning, and number of air changes per hour at 50 Pa are

found to have a positive effect on the electricity consumption. On the other hand, the average number of weeks that the family leaves for vacation and the existence or not of an air conditioning system have a negative effect on the electricity.

Sanquist et al. (2012) base their research on data from the Residential Energy Consumption Survey (RECS) conducted on 2005 in the USA. The air-conditioning, laundry usage, personal computers, climate zone of dwelling, and TV use significantly influence the electricity consumption. Kavousian et al. (2013) examine the residential electricity consumption of 952 US dwellings in a view of daily maximum and minimum. Daily minimum consumption is influenced by weather, location, dwelling size, and the number of refrigerators when daily maximum consumption is influenced by the use of appliances that consume a lot and the number of residents. In the summer model, the primary factor that influences the electricity consumption is the cooling degrees days.

Tewathia (2014) conducts a survey in Delhi to find the determinants of electricity consumption. The household income, the number and the usage of electrical appliances, the size of the house, the family size, time spent out of the house, and the higher educational level influence the monthly electricity consumption through all the seasons. The educational level has a negative relationship as the higher educated families tend to consume less electricity. Filippini and Pachauri (2004) analyze the electricity demand in urban Indian households. The price is inelastic in electricity demand, so the price is not an inhibiting factor in residential electricity consumption. The income, the size, the regions, and the degrees of urbanity have a significant influence into the electricity consumption. Dwellings with more residents and younger households head had the tendency to consume less electricity from those that had less elder people.

Jones et al. (2015) conduct a broad literature review to investigate the factors that influence or not the domestic electricity consumption. They study 62 factors as potential factors that determine the electricity consumption. In relation to socio-economic factors, the higher household and disposable income, the more occupants and presence of teenagers have a positive effect on electricity consumption. In relation to dwelling factors, the dwelling age, the number of rooms, the number of bedrooms, and the floor area influence the electricity consumption. Regarding appliance factors, the following ones have a positive effect: more appliances, the existence of desktop computer, television, electric oven, refrigerator, dishwasher, tumble dryer, and higher use of washing machines and tumble dryer.

Esmaeilimoakher et al. (2016) accomplish an introduction to the factors that influence the electricity consumption. Their analysis is based on a survey conducted in nine households of Perth of Western Australia. The main results are that the average annual electricity consumption per person per m^2 floor area (AAEC/P m^2) has a negative correlation with the number of occupants and the dwellings size.

Studies regarding Greece

The research in the field of socio-economic determinants that influence electricity consumption in Greece is poor. There are a lot of works focused on macroeconomic factors that determine energy consumption. Only the study of Sardianou (2007) provides research that includes demographic data and examines electricity conservation behavior.

Donatos and Mergos (1991) examine the residential electricity demand in Greece during the period 1961–1986. Data are collected from a public database. It is found that the electricity demand is price inelastic and income elastic. The sales of appliances, as well as the heating degrees-days, are found to have an insignificant effect on electricity demand in contrast with the number of consumers that has a significant effect.

Hondroyiannis (2004) examines the elasticity of price and income in long-run and short-run demand for residential electricity. The examined period is 1986–1999 employing monthly data. In the short-run, the electricity demand is income inelastic and independent of the price, while in the long-run period, all variables, income, price, and weighted average temperature are found to affect electricity demand.

Polemis and Dagoumas (2013) conduct a similar with Hondroyiannis (2004) research. They use cointegration techniques and the vector error correction model to observe the long-run and short-run electricity demand. The data that are taken into account are for a longer period, from 1970 to 2011. In the long-run, the electricity demand is price inelastic and income elastic, while in the short-run the relevant elasticities are inelastic.

Sardianou (2007) investigates the determinants of household energy conservation. The analysis is based on a survey that has been conducted in 586 households of five main Athens' regions. One of the findings is that people with higher income that own their houses, and have a large family are more willing to conserve energy. Also, the number of rooms, the dwelling's size, sex, educational level, and marital status are found that do not have a significant influence in energy conservation. However, it is found that the larger electricity expenditures negatively influence the energy conservation behaviors and the older people are more energy-intensive users than the younger ones.

All variables that have been studied in the above papers are indicated in Tables 6 and 7 in the Appendix section. Tables 6 and 7 also present which of these variables have been studied in this paper.

Method

Model specification

The ordinary least squares (OLS) regression is used to estimate the determinants that affect the electricity consumption in Greek households. A variety of studies that examined the determinants of electricity consumption have been conducted using OLS regression (Bedir et al., 2013; Brounen et al., 2012; Filippini & Pachauri, 2004; Gram-Hanssen, 2011; Halicioglu, 2007; Kavousian et al., 2013; McLoughlin et al., 2012; Ndiaye & Gabriel, 2011; Sanquist et al., 2012; Sardianou, 2007; Wiesmann et al., 2011). Two different models are employed to determine the electricity consumption. More specifically, a simple OLS regression model and a log-linear regression model are used to build the aforementioned models.

Data sources and description

Data are collected from a Greek electricity provider and refer only to residential dwellings. Data for the consumption and square meters area have been provided through the actual bills. The period of actual bills is not the same between bills and differs among dwellings. Thus, in order to calculate the consumption with accuracy, the consumption

per day is calculated at first. Afterwards, consumption per month is calculated and only dwellings that have consumption 2017 are selected.

Demographics and behavior data are retrieved from a questionnaire that was provided through the electricity provider's online platform. The questionnaire was answered from every individual that covers the bill. Only dwellings that already had a monthly consumption for 2017 and have also answered all the questions are selected. The dwellings with invalid values have been excluded from the data, so the final number of dwellings that are included in the analysis is 1801. Table 1 illustrates all available variables, as well as the type and the units of the variables of both models. Table 2 illustrates the summary of statistics of the variables of both models and it shows the levels of ordinal variables and their correspondence to the converted numbers. In addition, the factor type of each variable is indicated.

In the literature review, we have found out that many studies (Donatos & Mergos, 1991; Kavousian et al., 2013; Ndiaye & Gabriel, 2011; Sanquist et al., 2012; Wiesmann et al., 2011) include in their models the weather factors of heating degrees-days (HDD) and cooling degrees-days (CDD). HDD and CDD is the difference, in degrees, of outside temperature and base (18.3 °C) temperature. HDD and CDD data for each prefecture and for 2017 have been downloaded from the weather stations of National Observatory of Athens (NOA). Data have been available in the weather website (www.meteo.gr) and have been recorded at a daily basis (Petrou, 2018). The yearly HDD and CDD have been calculated per prefecture and the weather data are then connected to the consumption data based on prefecture. Units of HDD and CDD are in 1000 °C days (the values of these variables are big numbers and they should be fitted in the model as in Wiesmann et al., 2011).

The data preparation, manipulation, visualization, and the regression analysis is conducted using programming language R through RStudio program.

The Model

Before conducting a regression analysis, an advanced statistical analysis is conducted to observe any associations or correlation between variables. Thus, pairwise comparisons and a correlation analysis (correlation matrix can be found in Table 8 in the Appendix section) are used. The insights of the analysis show a very high negative correlation between HDD and CDD, approximately -0.809 (see Table 8), so HDD is removed from the model. Furthermore, a high correlation between family type and number of occupants is observed, so family type is removed from the model.

In the sample, the final independent variables along with the dummy variables count to thirty three (33). It is essential to determine whether the subset of all independent variables yields to an adequate and appropriate model. Stepwise regression is a method that attempts to find the best regression model, without examining all the possible models (Berenson et al., 2014). There are two approaches of stepwise regression, the "forward selection" and the "backward elimination". Both approaches use the Akaike Information Criterion (AIC) to find the best combination of variables based on balancing the model's complexity and accuracy. The best model is the one with minimum AIC value. The regression model is built using the forward selection, where an initial model is defined that contains only the constant and each independent variable is

Table 1 Model specification and variable definitions

Variable	Type	Unit	Variable	Type	Unit
Ave. consumption	Continuous	kWh/month	Time spend	Ordinal	
Square meters area	Continuous	m ²	Lights:	Cat. nominal	
Occupants	Discrete		Never		Ref. category
Family type:	Cat. nominal		Often		Dummy
Young people		Ref. category	Sometimes		Dummy
Family with older children		Dummy	Heating type:	Cat. nominal	
Family with young children		Dummy	Central boiler		Ref. category
Older people		Dummy	Individual cent. boiler		Dummy
Age	Cat. nominal		Individual local units		Dummy
Gender:		Categorical	No heating		Dummy
Female		Ref. category	Secondary heater:	Cat. nominal	
Male		Dummy	No		Ref. category
Marital status:	Cat. nominal		Yes		Dummy
Divorced		Ref. category	Heating hours	Ordinal	
Married		Dummy	Cooling type:	Cat. nominal	
Single		Dummy	No air-conditioning		Ref. category
Widowed		Dummy	Have air-conditioning		Dummy
Occupants' work	Discrete		Cooling hours:	Ordinal	

Table 1 Model specification and variable definitions (Continued)

Variable	Type	Unit	Variable	Type	Unit
Income	Ordinal	€/year	Summer holidays:	Cat. nominal	Ref. category
Educational level	Ordinal		Other		
House status:	Cat. nominal		I don't take sum. hol.		Dummy
Rent		Ref. category	July/August		Dummy
Own		Dummy	June/September		Dummy
Dwelling type:	Cat. nominal		Winter holidays:	Cat. nominal	
Block of flats		Ref. category	Other		Ref. category
Single family house		Dummy	Christmas		Dummy
Dwelling floor	Ordinal		Easter		Dummy
Rooms	Ordinal		I don't take win. hol.		Dummy
Bedrooms	Ordinal		HDD		10 ³ °C days
Model	Equation				
Model 1	$C = \beta_0 + \beta_1 SM + \beta_2 O + \beta_3 FM + \beta_4 A + \beta_5 G + \beta_6 MS + \beta_7 OW + \beta_8 I + \beta_9 EL + \beta_{10} + \beta_{11} DT + \beta_{12} R + \beta_{13} B + \beta_{14} TS + \beta_{15} L + \beta_{16} HT + \beta_{17} SH + \beta_{18} HH + \beta_{19} CT + \beta_{20} CH + \beta_{21} SHol + \beta_{22} WHol + \beta_{23} CDD + \varepsilon$				
Model 2	$\ln C = \beta_0 + \beta_1 SM + \beta_2 O + \beta_3 FM + \beta_4 A + \beta_5 G + \beta_6 MS + \beta_7 OW + \beta_8 I + \beta_9 EL + \beta_{10} HS + \beta_{11} DT + \beta_{12} R + \beta_{13} B + \beta_{14} TS + \beta_{15} L + \beta_{16} HT + \beta_{17} SH + \beta_{18} HH + \beta_{19} CT + \beta_{20} CH + \beta_{21} SHol + \beta_{22} WHol + \beta_{23} CDD$				
Abbreviation	C consumption, SM square meters area, O occupants, FM family type, A age, G gender, MS marital status, OW occupants' work, I income, EL educational level, HS house status, DT dwelling type, R rooms, B bedrooms, TS time spend, L lights, HT heating type, SH secondary heater, HH heating hours, CT cooling type, CH cooling hours, SHol summer holidays, WHol winter holidays, CDD cooling degrees days				

Note: Dummy variables take the value 1 if the variable is present at the specific dwelling and 0 if it is not

Table 2 Summary statistics of the variables

Variable	Mean	St. Dev.	Levels of ordinal variables	Factor type
Ave. consumption	396.49	223.645		
Square meters area	105.429	52.416		Dwelling factor
Occupants	3.062	1.143		Socio-economic factor
Family type: family with older children ^a	0.220	0.414		Socio-economic factor
Family type: family with young children ^a	0.443	0.497		Socio-economic factor
Family type: older people	0.091	0.287		Socio-economic factor
Age	2.592	0.828	1: "19–29", 2: "30–39", 3: "40–55", 4: "56–67", 5: "68+".	Socio-economic factor
Gender: male ^a	0.819	0.385		Socio-economic factor
Marital status: married ^a	0.778	0.416		Socio-economic factor
Marital status: single ^a	0.171	0.377		Socio-economic factor
Marital status: widowed ^a	0.008	0.091		Socio-economic factor
Occupants' work	1.532	0.702		Socio-economic factor
Income	2.253	0.857	1: Low-income (less than 10,000€), 2: Lower-middle (11,000€–20,000€), 3: Upper-middle (21,000€–40,000€), 4: High-income (more than 41,000€)	Socio-economic factor
Educational level	2.835	0.831	1: "No diploma", 2: "High school diploma or equivalent", 3: "Bachelor or equivalent", 4: "Master or equivalent", 5: "Doctoral or equivalent"	Socio-economic factor
House status: own ^a	0.721	0.449		Dwelling factor
Dwelling type: block of flats ^a	0.710	0.454		Dwelling factor
Dwelling type: single family house ^a	0.290	0.454		Dwelling factor
Dwelling floor	2.189	0.813	1: "1–2", 2: "3–4", 3: "5–6", 4: "7–8"	Dwelling factor
Rooms	2.149	0.635	1: "1–2", 2: "3–4", 3: "5 or more"	Dwelling factor
Bedrooms	1.919	0.416	1: "1", 2: "2–3", 3: "4 or more"	Dwelling factor
Time spend	2.212	0.548	1: "Less than half-day", 2: "Half-day or more", 3: "All day"	Socio-economic factor
Lights: often ^a	0.043	0.202		Dwelling factor

Table 2 Summary statistics of the variables (*Continued*)

Variable	Mean	St. Dev.	Levels of ordinal variables	Factor type
Lights: sometimes ^a	0.400	0.490		Dwelling factor
Heating type: individual central boiler ^a	0.503	0.500		Dwelling factor
Heating type: individual local units ^a	0.284	0.451		Dwelling factor
Heating type: no heating ^a	0.053	0.224		Dwelling factor
Secondary heater: yes ^a	0.722	0.448		Dwelling factor
Heating hours	2.351	0.911	1: "0–2 h", 2: "2–5 h", 3: "5–10 h", 4: "10 h or more"	Dwelling factor
Cooling type: have air-conditioning ^a	0.870	0.336		Dwelling factor
Cooling hours ^a	1.809	0.832	1: "0–2 h", 2: "2–5 h", 3: "5–10 h", 4: "10 h or more"	Dwelling factor
Summer holidays: I don't take summer holid. ^a	0.154	0.361		Socio-economic factor
Summer holidays: July/August ^a	0.668	0.471		Socio-economic factor
Summer holidays: June/September ^a	0.087	0.281		Socio-economic factor
Winter holidays: Christmas ^a	0.234	0.424		Socio-economic factor
Winter holidays: Easter ^a	0.082	0.275		Socio-economic factor
Winter holidays: I don't take winter holid. ^a	0.527	0.499		Socio-economic factor
CDD (1000)	1.233	0.233		Weather factor
HDD (1000)	1.113	0.397		Weather factor

^aDummy variable

retained in the model only if it improves the ability of the model to predict the dependent variable.

Results and discussion

The OLS regression method

The results of the OLS regressions are presented in Table 3. In general, the results from both models are in agreement with the literature, as it will be indicated in this section. Most of the significant variables are common in both models, but there are variables that influence one model and not the other. The log-linear model (model 2) has better goodness of fit from the linear model, in terms of the R^2 . Both models explain

Table 3 Estimation results from OLS regression model

Variable	Model 1 Ave. consumption	Model 2 log(Ave. consumption)
Squ. meter area	1.389*** (0.096)	0.003*** (0.0002)
Heating hours	36.760*** (5.537)	0.075*** (0.013)
Occupants	41.054*** (4.211)	0.132*** (0.010)
Heating type: individual central boiler	−17.433 (12.890)	−0.016 (0.031)
Heating type: individual local units	46.011*** (14.447)	0.093*** (0.035)
Heating type: no heating	11.460 (22.608)	0.003 (0.055)
Cooling hours	20.100*** (5.808)	0.058*** (0.015)
Time spend: half-day or more		−0.067*** (0.025)
Time spend: less than half-day		−0.184*** (0.047)
Cooling type: no air-conditioning		−0.090** (0.035)
Age	18.028*** (5.502)	0.033** (0.013)
Secondary heater: yes	28.585*** (10.182)	0.074*** (0.025)
Dwelling type: single family house	23.868** (10.716)	
CDD	44.644** (20.785)	0.106** (0.051)
Constant	−132.703*** (37.733)	4.633*** (0.100)
Observations	1,801	1,801
R^2	0.290	0.297
Adjusted R^2	0.286	0.292
Residual Std. error	189.006 (df = 1789)	0.458 (df = 1787)
F statistic	66.475*** (df = 11; 1789)	58.086*** (df = 13; 1787)

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

approximately 30% of the variance in electricity consumption. Even if this value does not seem satisfactory for a regression analysis, when comparing to the literature the R^2 is within the range published. Indeed, in Sardanou (2007), R^2 is approximately 10%; in Wiesmann et al. (2011), R^2 is approximately 33%; in Bedir et al. (2013), R^2 is approximately 50%; and in most other papers presented in the literature review, the R^2 value has not been given. One basic reason for this low value is that even though we have studied thirty-three variables (most given by the electricity provider and others found by the authors), more parameters need to be studied.

Square meters area has a significant effect on the average monthly electricity consumption in both models. To be more specific, if the square meters area increases by 1m^2 then an increase of 1.389 kWh/month according to model 1 and an increase on average yearly consumption by 0.3% according to model 2 are expected. These results are in line with previous studies (Bedir et al., 2013; Filippini & Pachauri, 2004; Gram-Hanssen, 2011; Jones et al., 2015; Kavousian et al., 2013; Tewathia, 2014; Wiesmann et al., 2011).

Number of occupants is strongly related with the electricity consumption (because of high beta coefficient and p -value < 0.01). In both models, more occupants consume more electricity. Studies of Gram-Hanssen (2011), Jones et al. (2015), Kavousian et al. (2013), and Ndiaye and Gabriel (2011) reach the same conclusion.

Heating hours, heating type, and the presence of secondary heaters have a significant positive effect on electricity consumption in both models. That is, heating hours

influence the electricity consumption regardless the heating type. On the other hand, heating type of local units significantly influences the electricity consumption. Dwellings that use local units for heating the space seem to consume more electricity. The results reveal that houses with heating type of local units use possibly electrical appliances to heat their space which has an impact on their total consumption. The presence of secondary heaters has also a significant positive effect on the electricity consumption. Those results enhance the perspective that the electrical appliances used to heat the space have an impact on electricity consumption. Jones et al. (2015) mention that there are eight studies that found a positive effect of presence of electric space heating system on electricity consumption.

Cooling hours is also related with the electricity consumption. Both models agree to the positive relationship between cooling hours and electricity consumption, as expected. CDD also is found that has a positive effect on electricity consumption in both models. The presence of air-conditioning to cool the space has a significant effect in model 2 while in model 1 it is not found that influences the electricity consumption. This result is aligned with the literature review presented by Jones et al. (2015), since they present studies with both results.

According to model 1, the dwelling type has a significant effect on electricity consumption, as the single family houses seem to consume more electricity. This result is aligned with past studies of Bedir et al. (2013), Brounen et al. (2012), McLoughlin et al. (2012), and Wiesmann et al. (2011).

Both models reveal that the age of inhabitants positively influences the electricity consumption. So, as long as the occupants that cover the bill are elderly, the more electricity is consumed. This result is aligned with and also mentioned that there are eight studies that marked the positive effect of age of head of the household on the electricity consumption.

According to model 2, dwellings with occupants that spent more time in home are found to have a positive significant effect on electricity consumption, as it is expected and it is aligned with Ndiaye and Gabriel (2011) and Tewathia (2014), respectively.

Many variables of the collected data are found that have no significant influence on the electricity consumption. Those variables are gender, educational level, house status, marital status, dwelling floor, income, light behavior, and summer holidays.

As mentioned above, most of the variables that are found significant are common in both models, but there are variables that influence one model and not the other. This happens because in model 2 a non-linear relationship exists between the independent and dependent variables.

Two-stage least squares method (2SLS)

It is possible that a two-way causation exists between variables of the above models; thus, there is the need to test for endogeneity. Variables that are tested for endogeneity are those of square meter area, number of occupants, and heating hours. Square meter area is found as significant at the level of 10%; thus, 2SLS is conducted with endogenous variable the square meters area. Number of bedrooms and number of rooms have been inserted in the model as instrumental variables. Tables 4 and 5 illustrate the results of OLS, first stage of 2SLS and second stage of 2SLS for model 1 and model 2, respectively. The coefficients of square meter area and other variables have been fitted and the significant variables are the same with the OLS method.

Table 4 Estimation results from 2SLS model 1

<i>Dependent variable:</i>	OLS estimation Ave. consumption	2SLS estimation—first stage Squ. meter area	2SLS estimation—second stage Ave. consumption
Squ. meter area	1.389*** (0.096)		
Squ. meter area_hat			1.739*** (0.206)
Heating hours	36.760*** (5.537)	5.022*** (1.209)	34.778*** (5.654)
Occupants	41.054*** (4.211)	2.616*** (0.970)	37.367*** (4.646)
Heating type: individual central boiler	−17.433 (12.890)	5.673** (2.824)	−20.316 (13.025)
Heating type: individual local units	46.011*** (14.447)	−3.165 (3.180)	47.131*** (14.513)
Heating type: no heating	11.460 (22.608)	−4.579 (4.958)	14.886 (22.763)
Cooling hours	20.100*** (5.808)	−2.594* (1.337)	20.739*** (5.839)
Age	18.028*** (5.502)	1.081 (1.213)	16.671*** (5.568)
Secondary heater: yes	28.585*** (10.182)	−1.282 (2.253)	28.256*** (10.221)
Dwelling type: single family house	23.868** (10.716)	22.279*** (2.313)	12.061 (12.403)
Cooling type: no air-conditioning		−2.776 (3.193)	
Bedrooms		42.101*** (2.934)	
Rooms		16.977*** (1.816)	
CDD	44.644** (20.785)	12.749*** (4.573)	40.139* (20.995)
Constant	−132.703*** (37.733)	−52.396*** (9.422)	−141.065*** (38.125)
Observations	1801	1801	1801
R^2	0.290	0.381	0.285
Adjusted R^2	0.286	0.376	0.280
Residual Std. error	189.006 (df = 1789)	41.402 (df = 1787)	189.710 (df = 1789)
F statistic	66.475*** (df = 11; 1789)	84.476*** (df = 13; 1787)	

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Conclusions

This study focuses on the investigation of the socio-economic determinants, the dwellings characteristics, and the climatic conditions that influence the household electricity consumption. Two regression models, one linear and one log-linear, are built and the results have been presented in the previous section. The two-stage least squares method (TSLS) is used to explore the two-way causation of squared meter area. Most significant variables are the number of occupants, the size of the dwelling, the heating type, the heating and cooling hours, and the weather conditions. The results of this study are aligned with the ones presented in the literature review.

When acknowledging the conclusions of this analysis, policy makers could use suitable incentives to motivate customers to reduce their electricity consumption. The variables regarding heating and cooling the space are found as significant in both models. A good practice would be for the government to motivate people to renovate their houses in order to maintain the houses' temperature and as a consequence it could reduce the cooling and heating electricity demand. As it is shown from this study, in Greece, houses use electricity to heat their spaces and in many cases they use secondary heaters. Thus, another measure could be to give a subsidy

Table 5 Estimation results from 2SLS model 2

<i>Dependent variable:</i>	OLS estimation	2SLS estimation—first stage	2SLS estimation—second stage
	log(Ave. consumption)	Squ. meter area	log(Ave. consumption)
Squ. meter area	0.003*** (0.0002)		0.005*** (0.0005)
Occupants	0.132*** (0.010)	2.616*** (0.970)	0.111*** (0.011)
Heating hours	0.075*** (0.013)	5.022*** (1.209)	0.058*** (0.014)
Cooling hours	0.058*** (0.015)	−2.594* (1.337)	0.065*** (0.015)
Time spend: half-day or more	−0.067*** (0.025)		−0.077*** (0.026)
Time spend: less than half-day	−0.184*** (0.047)		−0.181*** (0.048)
Cooling type: no air-conditioning	−0.090** (0.035)	−2.776 (3.193)	−0.082** (0.036)
Bedrooms		42.101*** (2.934)	
Rooms		16.977*** (1.816)	
Secondary heater: yes	0.074*** (0.025)	−1.282 (2.253)	0.076*** (0.025)
Heating type: individual central boiler	−0.016 (0.031)	5.673** (2.824)	−0.031 (0.032)
Heating type: individual local units	0.093*** (0.035)	−3.165 (3.180)	0.102*** (0.036)
Heating type: no heating	0.003 (0.055)	−4.579 (4.958)	0.012 (0.056)
CDD	0.106** (0.051)	12.749*** (4.573)	0.092* (0.052)
Dwelling type: single family house		22.279*** (2.313)	
Age	0.033** (0.013)	1.081 (1.213)	0.022 (0.014)
Constant	4.633*** (0.100)	−52.396*** (9.422)	4.585*** (0.102)
Observations	1,801	1,801	1,801
R^2	0.297	0.381	0.270
Adjusted R^2	0.292	0.376	0.265
Residual Std. error (df = 1787)	0.458	41.402	0.467
F Statistic (df = 13; 1787)	58.086***	84.476***	

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

to urge consumers to change their heating systems to more efficient and cheaper ones, such as natural gas boilers.

Another strategy that policy makers could follow is to incentivize electricity providers for the electricity per hh reduction. The utilities then could provide a discount to those households that achieve an electricity reduction year by year. Thus, both utilities and consumers will win from this strategy. The customers will have the incentive of lower cost and will try to reduce their consumption.

Simultaneously, government and utilities could enhance and promote the usage of new technology electricity appliances, such as smart appliances and appliances with A++ energy label, that consume less electricity. By large campaigns, the consumers could be informed about how they can save if they change their old wasteful appliances.

To conclude, this research shows that the dwelling and household characteristics, as well as the climatic conditions, are essential predictors in models of electricity consumption. Further research on occupants' behavior and on presence and functions of appliances will enhance the determinants of electricity consumption in housing.

Appendix

Table 6 Variables studied in the literature as it is presented in the “Literature review” section and variables that are analyzed in this study

a/a	Variable	Studies that consider the variable	This study considers the variable
1	Number of occupants	Wiesmann et al., 2011; Brounen et al., 2012; Gram-Hanssen, 2011; Esmailimoakher et al., 2016; Sanquist et al., 2012; Ndiaye & Gabriel, 2011; Tewathia, 2014; Sardianou, 2007	✓
2	Number/ Presence of children	Wiesmann et al., 2011; Bedir et al., 2013; Brounen et al., 2012; Gram-Hanssen, 2011; Esmailimoakher et al., 2016	✓
3	Number/Presence of teenagers	Brounen et al., 2012; Gram-Hanssen, 2011	✓
4	Number/Presence of adults	McLoughlin et al., 2012	✓
5	Number/Presence of elderly people (over 65 years old)	McLoughlin et al., 2012; Bedir et al., 2013; Brounen et al., 2012; Gram-Hanssen, 2011	✓
6	Age of Household Reference Person (HRP)	McLoughlin et al., 2012; Bedir et al., 2013; Brounen et al., 2012; Gram-Hanssen, 2011; Esmailimoakher et al., 2016; Ndiaye & Gabriel, 2011; Sardianou, 2007;	✓
7	Age of children	Ndiaye and Gabriel (2011)	✓
8	Gender of Household Reference Person	Esmailimoakher et al., 2016; Sardianou, 2007	✓
9	Marital status of occupants	Sardianou, 2007	✓
10	Employment status of HRP	Bedir et al., 2013	
11	Hours of occupancy (or number of occupants work or stay at home)	Bedir et al., 2013; Ndiaye & Gabriel, 2011; Polemis & Dagoumas, 2013	✓
12	Time spend outside/inside home	Esmailimoakher et al., 2016; Tewathia, 2014	✓
13	Education level of HRP	Bedir et al., 2013; Gram-Hanssen, 2011; Ndiaye & Gabriel, 2011; Tewathia, 2014; Sardianou, 2007	✓
14	Social classification of HRP	McLoughlin et al., 2012	
15	Family type	Wiesmann et al., 2011; McLoughlin et al., 2012; Brounen et al., 2012	✓
16	Fraction of females in household	Brounen et al., 2012	
17	Occupied by foreign-born	Brounen et al., 2012; Ndiaye & Gabriel, 2011	
18	Income	Wiesmann et al., 2011; Bedir et al., 2013; Brounen et al., 2012; Gram-Hanssen, 2011; Halicioglu, 2007; Esmailimoakher et al., 2016; Ndiaye & Gabriel, 2011; Tewathia, 2014; Donatos & Mergos, 1991; Hondroyannis, 2004; Sardianou, 2007	✓
19	Dwelling type	Wiesmann et al., 2011; Bedir et al., 2013; McLoughlin et al., 2012; Brounen et al., 2012; Gram-Hanssen, 2011; Esmailimoakher et al., 2016; Ndiaye & Gabriel, 2011	✓
20	Dwelling age	Wiesmann et al., 2011; Brounen et al., 2012; Esmailimoakher et al., 2016; Sanquist et al., 2012; Ndiaye & Gabriel, 2011;	
21	Dwellings per building or Dwellings density	Wiesmann et al., 2011	
22	Dwelling size	Bedir et al., 2013; Brounen et al., 2012; Gram-Hanssen, 2011; Esmailimoakher et al., 2016; Tewathia, 2014	✓

Table 6 Variables studied in the literature as it is presented in the “Literature review” section and variables that are analyzed in this study (*Continued*)

a/a	Variable	Studies that consider the variable	This study considers the variable
23	Number of rooms	Wiesmann et al., 2011; Bedir et al., 2013; Brounen et al., 2012; Sardianou, 2007	✓
24	Number of bedrooms	McLoughlin et al., 2012; Bedir et al., 2013; Esmailimoakher et al., 2016	✓
25	Number of study rooms	Bedir et al., 2013	
26	Dwelling floor (in case of apartment building)		✓
27	Heating system	Bedir et al., 2013; Brounen et al., 2012; Gram-Hanssen, 2011; Ndiaye & Gabriel, 2011	✓
28	Heating system efficiency	Ndiaye & Gabriel, 2011	
29	Hours of heating per day		✓
30	Presence of secondary heater appliances		✓
31	Age of the heating system	Ndiaye & Gabriel, 2011	
32	Type of air conditioning system	Ndiaye & Gabriel, 2011, Sanquist et al., 2012	
33	Presence of air conditioning system	Ndiaye & Gabriel, 2011	✓
34	Age of the air conditioning system	Ndiaye & Gabriel, 2011	
35	Hours of cooling per day		✓
36	Rented/owner occupied	Bedir et al., 2013; Ndiaye & Gabriel, 2011; Sardianou, 2007	✓
37	Years of residence in the same house	Bedir et al., 2013; Esmailimoakher et al., 2016	
38	Maintenance interior or exterior / Insulation quality	Brounen et al., 2012	
39	Heating degrees-days	Wiesmann et al., 2011; Sanquist et al., 2012; Donatos & Mergos, 1991; Polemis & Dagoumas, 2013	✓
40	Cooling degrees-days	Wiesmann et al., 2011; Sanquist et al., 2012; Polemis & Dagoumas, 2013	✓
41	Temperature	Hondroyiannis, 2004	
42	Number of hours windows were open in the dwelling	Esmailimoakher et al., 2016	
43	Average number of weeks of vacation taken away from the house each year (or summer/winter holidays)	Ndiaye & Gabriel, 2011	✓
44	Household awareness (The education level of the head of the household is used as a proxy for household awareness)	Tewathia, 2014	
45	Place/Location	Wiesmann et al., 2011; Tewathia, 2014; Halicioglu, 2007	
46	Electricity price	Halicioglu, 2007; Donatos & Mergos, 1991; Hondroyiannis, 2004; Polemis & Dagoumas, 2013; Sardianou, 2007	
47	Electricity tariff (can take two values: (1) single tariff consumption—one daytime and evening rate on weekdays and weekends, and (2) double tariff consumption—two different rates, one for during the day and another for evenings, nights and weekends)	Bedir et al., 2013	
48	Price of diesel or LPG (liquefied petroleum gas) or light fuel	Donatos & Mergos, 1991; Polemis & Dagoumas, 2013	

Table 6 Variables studied in the literature as it is presented in the “Literature review” section and variables that are analyzed in this study (*Continued*)

a/a	Variable	Studies that consider the variable	This study considers the variable
49	Gross domestic product (GDP)	Polemis & Dagoumas, 2013	
50	Price of electrical appliances	Donatos & Mergos, 1991	
51	Gas consumption, yearly	Bedir et al., 2013	
52	Number of appliances and number of appliances per group	Wiesmann et al., 2011 ; Bedir et al., 2013	
53	Lights (hours per day light bulbs are on/ type) or Leave lights on in unoccupied room	Sanquist et al., 2012 ; Ndiaye & Gabriel, 2011	✓
54	Use of appliances (Total use of electrical appliances in a day (in hours))	Tewathia, 2014	
55	Number of light bulbs	Bedir et al., 2013	
56	Computer (number, use)	Sanquist et al., 2012	
57	TV (number)	Sanquist et al., 2012	
58	Electric oven (use)	Sanquist et al., 2012	
59	Dishwasher (use)	Bedir et al., 2013 ; Sanquist et al., 2012	
60	Washing machine (use)	Bedir et al., 2013 ; Sanquist et al., 2012	
61	Tumble dryer (use)	Bedir et al., 2013 ; Sanquist et al., 2012	
62	Number of showers	Bedir et al., 2013	
63	Duration of showers	Bedir et al., 2013	
64	Ventilation system	Bedir et al., 2013	
65	Water heating type(electric/no electric)	McLoughlin et al., 2012	
66	Cooking type (electric/ no electric)	McLoughlin et al., 2012	
67	Efficiency (HoH who believe they can cut electricity consumption by x%)	McLoughlin et al., 2012	
68	Number of ceiling fans	Sanquist et al., 2012	
69	Cooled area	Sanquist et al., 2012	

Table 7 Low importance variables studied in the literature

a/a	Variable	Studies that consider the variable
1	Importance to reduce the amount of energy use	Ndiaye and Gabriel (2011)
2	Importance to spend less money on energy bills	Ndiaye and Gabriel (2011)
3	Feeling of the level of involvement of the government with energy conservation	Ndiaye and Gabriel (2011)
4	Interest in learning more about ways to save energy in the house	Ndiaye and Gabriel (2011)
5	Interest in using an eventual computer software that could serve to program and control the amount of energy used in the house	Ndiaye and Gabriel (2011)
6	Feeling of the safety of the neighborhood	Ndiaye and Gabriel (2011)
7	Insecurity and fear of crime	Ndiaye and Gabriel (2011)
8	Number of new major energy efficient appliances purchased over the last 5 years	Ndiaye and Gabriel (2011)
9	Type of fuel per appliance (oven, cloth dryer, pool heater)	Ndiaye and Gabriel (2011)
10	Renovation the last 5-10 years	Ndiaye and Gabriel (2011)
11	Type of fuel for the heating system/water heating	Ndiaye and Gabriel (2011)
12	Number of floors	Ndiaye and Gabriel (2011)
13	Presence of window overhangs (in each direction)	Ndiaye and Gabriel (2011)
14	Amount willing to spend on a new energy device if it would result in long term reductions in energy costs	Ndiaye and Gabriel (2011)
15	Effective U-value of windows/doors/walls/ceiling (Btu/h ft ² ° F)	Ndiaye and Gabriel (2011)
16	Ceiling area	Ndiaye and Gabriel (2011)
17	Total net exterior wall are	Ndiaye and Gabriel (2011)
18	Total window area	Ndiaye and Gabriel (2011)
19	Foundation/Basement wall U-value	Ndiaye and Gabriel (2011)
20	Number of air changes per hour at 50 Pa	Ndiaye and Gabriel (2011)
21	The respondent is informed about the global environmental problems	Sardianou (2007)
22	The respondent recognizes his contribution to environmental problems	Sardianou (2007)

In the following table, the correlation matrix between types of variables is presented. Due to the varying type of variables, a compass correlation matrix is created as follows:

- Continuous/discrete/ordinal pair: Pearson correlation
- Continuous/discrete/categorical pair: correlation coefficient or squared root of R^2 coefficient of linear regression of integer/numeric variable over factor/categorical variable. The value lies between 0 and 1.
- Categorical pair: Cramer's V value is computed based on Chi-squared test using. The value lies between 0 and 1.

The cutoff point is set 0.6. So, the variables of Family type and HDD are omitted from the analysis.

Table 8 Correlation matrix

	Ave Consump tion	Sq Meter Area	Occupants	Family Ty pe	Age	Gender	Marital Stat us	Occupants Work	Income	Educational Level	Household Size	Dwelling Ty pe	Dwelling Fi or	Rooms	Bedrooms	TimeSpent	Light	Heating Ty pe	Secondary Heater	Heating Ho urs	Cooling Ty pe	Cooling Ho urs	Summer Ho idays	Winter Ho idays	HDD	CDD
Ave Consumption	1																									
Sq Meter/Area	0.423	1																								
Occupants	0.332	0.303	1																							
Family Type	0.269	0.242	0.71	1																						
Age	0.153	0.136	0.125	0.568	1																					
Gender	0.028	0.002	0.019	0.083	0.014	1																				
Marital Status	0.216	0.23	0.55	0.338	0.379	0.164	1																			
Occupants Work	0.108	0.143	0.362	0.383	-0.175	0.048	0.247	1																		
Income	0.183	0.286	0.288	0.213	0.186	0.005	0.275	0.224	1																	
Educational Level	0.037	0.142	-0.016	0.1	-0.085	0.042	0.079	0.121	0.324	1																
Household Size	0.146	0.174	0.229	0.311	0.28	0.051	0.2	0.028	0.097	0.013	1															
Dwelling Type	0.212	0.343	0.137	0.176	0.127	0.014	0.038	0.009	0.002	0.08	0.183	1														
Dwelling Floor	0.065	-0.112	-0.033	0.073	-0.017	0.023	0.085	0.045	0.1	0.094	0.091	0.456	1													
Rooms	0.242	0.403	0.288	0.262	0.162	0.017	0.223	0.178	0.267	0.069	0.177	0.25	-0.058	1												
Bedrooms	0.327	0.527	0.427	0.364	0.141	0.001	0.33	0.203	0.287	0.111	0.233	0.236	-0.048	0.503	1											
TimeSpent	0.104	0.03	0.088	0.201	0.152	0.047	0.184	-0.261	-0.084	-0.09	0.007	0.001	-0.014	0.074	0.006	1										
Light	0.095	0.005	0.103	0.082	0.042	0.025	0.003	0.001	0.128	0.008	0.008	0.022	0.01	0.064	0.008	0.07	1									
Heating Type	0.108	0.143	0.155	0.107	0.082	0.005	0.116	0.095	0.147	0.085	0.075	0.042	0.008	0.077	0.143	0.048	0.038	1								
Secondary Heater	0.037	0.014	0.026	0.019	0.037	0.014	0.017	0.019	0.024	0.02	0.015	0.051	-0.087	0.039	0.005	0.023	0.013	0.151	1							
Heating Hours	0.266	0.169	0.183	0.204	0.082	0.031	0.2	0.083	0.059	-0.023	0.065	0.187	-0.075	0.112	0.128	0.153	0.082	0.205	0.053	1						
Cooling Type	0.106	0.032	0.048	0.08	0.061	0.002	0.137	0.001	0.153	0.034	0.121	0.098	0.131	0.085	0.072	0.017	0.071	0.074	0.189	0.035	1					
Cooling Hours	0.125	-0.017	-0.018	0.046	-0.011	0.001	0.076	-0.024	0.015	-0.028	0.028	0.069	0.034	0.018	-0.006	0.078	0.068	0.066	0.121	0.272	0.346	1				
Summer Holidays	0.054	0.054	0.08	0.125	0.15	0.088	0.084	0.17	0.26	0.189	0.021	0.131	0.153	0.079	0.089	0.14	0.049	0.069	0.021	0.039	0.115	0.039	1			
Winter Holidays	0.08	0.049	0.121	0.11	0.132	0.058	0.072	0.12	0.201	0.218	0.061	0.138	0.055	0.063	0.087	0.065	0.034	0.038	0.059	0.043	0.057	0.096	0.078	1		
HDD	0.028	0.005	0.138	0.107	0.058	0.08	0.113	0.011	-0.072	-0.055	0.052	0.094	-0.027	0.033	0.084	-0.05	0.018	0.201	0.075	0.248	0.137	-0.124	0.066	0.133	0.899	1
CDD	-0.048	-0.033	-0.151	0.122	-0.055	0.073	0.123	-0.019	0.073	0.06	0.075	0.135	0.077	-0.041	-0.098	-0.043	0.018	0.238	0.077	-0.218	0.142	0.155	0.159	0.125	-0.899	1

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Authors' contributions

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Availability of data and materials

Data of this study were collected from the database of a Greek electricity provider. The research data cannot be shared publicly, because the individual privacy could be compromised. The authors after the approval of the Greek electricity provider could provide the final data set to a third researcher.

Declarations

Competing interests

The authors declare that they have no competing interests.

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