The Economic and Social Review, Vol. 50, No. 2, Summer 2019, pp. 265-280

Household Energy Consumption: A Study of Micro Renewable Energy Systems in Ireland

Michael Chesser
Technological University Dublin

Jim Hanly
Technological University Dublin

Damien Cassells
Technological University Dublin

Nikolaos Apergis
University of Piraeus

Abstract: Ireland's National Renewable Energy Action plan addresses how it will meet its environmental commitments. One element of the strategy is the use and promotion of micro renewable energy systems (micro-RES). This paper profiles households that have adopted micro-RES and examines whether micro-RES installations have resulted in a reduction in energy consumption based on data from the Irish Household Budget Survey. Results indicate that the presence of micro-RES does not result in a reduction of electricity use, rather the opposite. Furthermore, our findings indicate that some revision of energy policy is needed, as the presence of micro-RES does not result in a decrease in total energy use.

I INTRODUCTION

The Irish government has stated its commitment to a low carbon energy future as part of its plan to support the wide scale deployment of renewable energy in

Acknowledgements: Financial support was provided by Fiosraigh Scholarship Programme awarded by TU Dublin. The authors are solely responsible for the content and the views expressed.

Corresponding author: michael.chesser@mydit.ie

the residential sector. Towards this end, several micro renewable energy systems[1] (micro-RES) and energy efficiency schemes have operated in Ireland. Currently there is the Solar PV Grant offered by Sustainable Energy Association of Ireland (SEAI) that offers a grant of up to €3,800 for solar PV panels and battery storage systems. There is also a Solar Thermal Grant with a value up to €1,200 (SEAI, 2017).

Households which integrate micro-RES could allow themselves to generate their own energy thus reducing energy demand, which in turn reduces the amount of new generation that needs to be built, resulting in lower costs to consumers. The promotion of micro-RES in Ireland could help it reach its energy policy goals while also contributing to its future energy demand. For example Allen *et al.* (2008) references a study where it was predicted that electrical micro-RES could provide 30 to 40 per cent of the UK's electricity needs by 2050.[2]

To support policymakers' decisions about how to reduce energy use and CO_2 emissions from the housing sector through the promotion of micro-RES, it is essential to know the profile of the average household that is currently adopting it. Also, it is worth investigating whether the adoption of micro-RES is successful in reducing domestic energy consumption. This paper addresses these issues by examining what the common household characteristics are among adopters of micro-RES using a Logit regression model. We also consider whether the growing number of micro-RES installations has had an impact on energy consumption levels for residential households in Ireland. Our results can inform the next generation of policy formulation and planning, particularly with regard to micro-RES in the Irish energy landscape. This study is significant for two reasons; firstly, no study, to the best of our knowledge, has yet to investigate how the growth of micro generation has impacted on residential energy consumption. Secondly, according to Jones *et al.* (2015) there is a shortage of studies which investigate the effects of the three main factors on residential energy demand in countries outside the US and UK.

The rest of the paper is structured as follows; Section II reviews the literature that examines the significant and insignificant factors impacting residential energy demand/consumption. Section III describes the data and the econometric methods. Our empirical findings are presented in Section IV. These findings are then discussed in the conclusion together with policy implications in Section V.

[1] There are many different types of micro-RES available to the residential sector; photovoltaic (PV) panels, micro wind turbines, solar thermal water heaters, wood pellet boilers, geothermal heat pumps or combined heat and power (CHP) units.

[2] The UK and Ireland share a similar climate; it would stand to reason that Ireland could reach these percentages as well.

II LITERATURE REVIEW

This study is concerned first with investigating what are the common household characteristics that have led to the adoption of micro-RES; and second whether the presence of micro-RES is a determinant of residential household energy use. As a result of this, the literature review will be presented in two parts; adoption of new energy sources and the determinants of residential energy consumption.

2.1 Adoption of New Energy Sources in the Residential Sector

There is a number of studies that examine the decision process for the adoption of a new energy source in the home. A study by Islam (2014) investigated whether Canadian households prefer the attributes of the new technology, solar PV and whether they are going to adopt it. Results show that younger households with higher technology awareness who are not as concerned with cost, are more likely to be in the early solar PV adoption rates. Mills and Schleich (2009) found that the adoption of solar thermal in Germany is higher in newer houses and in houses with more modern heating systems. While Michelsen and Madlener (2016) found that knowledge, house size, rural households and threats resulted in households adopting renewable heating systems. Variables that inhibited adoption were house age, comfort, status quo and homeowner with a university degree. Sopha *et al.* (2010), using Norwegian data, found that households with younger occupants and occupants with higher education levels were more likely to adopt heat pump or wood pellet as their future heating systems.

Studies on the adoption of renewable energy at household level in Ireland is limited, however there have been studies on Irish households' decisions regarding the adoption of different fuel sources and the adoption determinants of household appliances that improve energy efficiency. A study by McCoy and Curtis (2018) investigated the determinants of natural gas in the Irish residential sector. They found that socio-economic factors (SEF) such as lower levels of education and out of work households had lower rates of connections to gas lines. Another study by Leahy and Lyons (2010) examined the determinants of appliance ownership in the residential sector using the Irish Household Budget Survey (HBS). They modelled access to several appliances including double glazed windows. The authors' results were estimated using a Logit regression with findings showing that urban households are more likely to have double glazing than rural households. Another result of interest is the correlation with household disposable income which implies that, as income increases, so does the probability of having double glazing.

2.2 Determinants of Residential Energy Consumption

This subsection of the literature review presents studies that investigate the main determinants of residential energy consumption using econometric analysis with a focus firstly on global studies, followed by Irish studies on the main determinants

of residential energy. Jones, *et al.* (2015) compiled a comprehensive literature review of studies examining the variables that either have a significant or non-significant effect on residential energy demand/consumption (see Table 1). They broke down the variables into three groups; socio-economic factors (SEF),[3] dwelling factors (DF)[4] and appliance factors (AF).[5] The study found that, in the literature reviewed, 62 variables influence residential energy consumption. These include 13 socio-economic, 12 dwelling and 37 appliance factors.

However there are mixed results in the global literature with regards to the direction of the relationship between these variables and residential energy consumption. Reviewing the variable 'household with children' from the socio-economic factors group, it was found to vary across the literature. Several studies found that it had a positive effect on household energy consumption; McLoughlin *et al.* (2012) and Wiesmann *et al.* (2011). Meanwhile Bartiaux and Gram-Hanssen (2005) and Gram-Hanssen *et al.* (2004) found a negative effect. The following studies found no effect; Bedir *et al.* (2013) and Cramer *et al.* (1985).

There is also a debate on the direction of the relationship between several dwelling factors and energy consumption. For example, Brounen *et al.* (2012) and Leahy and Lyons (2010) find a positive effect with regards to the age of dwelling. A negative effect was found by Baker and Rylatt (2008) and Chong (2012), while Tso and Yau (2007) found no effect.

Finally, the literature on appliance factors again shows mixed findings. For example, looking at the relationship between the presence of tumble dryers in a home and energy consumption, a positive effect was found by Mcloughlin *et al.* (2012) while Carter *et al.* (2012) found no effect.

The following subsection details three Irish studies investigating the determinants of residential energy consumption. The first study is Leahy and Lyons (2010), which examined the determinants of energy use first by electricity use and then all other energy use. Their study used ordinary least squares regression analysis on the 2004/2005 Irish Household Budget Survey. Their energy use models included variables from SEF, DF and AF. McLoughlin *et al.* (2012), differed from Leahy and Lyons (2010) by using four different parameters as the dependent variable; total electricity consumption, maximum demand, load factor and time of use. McLoughlin *et al.* (2012) used a multiple linear regression on each model, using a sample of 3,941 Irish households. Their models included variables from SEF, DF and AF. Lastly Harold *et al.* (2015) investigates the daily residential gas demand by employing random effects estimator on a panel dataset of 1,181 households' smart meter data. Their daily residential gas demand models included variables from SEF, DF and weather variables.

[3] Includes variables such as; number of occupants, education level of head of household, income, tenure type, age of head of household, etc.

[4] Includes variables such as; type of dwelling, year of construction, size of dwelling, number of bedrooms, double glazing windows etc.

[5] Includes variables such as; total number of appliances, power demand appliances, etc.

Table 1: Summary of Studies

			Independent variable studied		
Study		*Country*	*SEF*	*DF*	*AF*
Larsen and Nesbakken	(2004)	Norway	X	X	X
Leahy and Lyons	(2010)	Ireland	X	X	X
Wiesmann, Azevedo, Ferrao and Fernandez	(2011)	Portugal	X	X	X
McLoughlin, Duffy and Conlon	(2012)	Ireland	X	X	X
Bartusch, Odlare, Wallin and Wester	(2012)	Sweden	X	X	
Zhou and Teng	(2013)	China	X	X	X
Belaid	(2016)	France	X	X	X
Huebner, Shipworth, Hamilton, Chalabi and Oreszczyn	(2016)	England	X	X	X
Iwafune and Yagita	(2016)	Japan	X	X	X
Matsumoto	(2016)	Japan	X	X	X
Wallis, Nachreiner and Matthies	(2016)	German	X	X	X
Copiello and Gabrielli	(2017)	Italy	X	X	
Harold, Cullinan and Lyons	(2017)	Ireland	X	X	

Source: Jones *et al.* (2015).

Common independent variables that had impact on energy use across all three studies were as follows. The dwelling factor; the number of rooms had a positive impact on energy use. Similar results were found for socio-economic factors, with households with a lower income or from a lower social group using less energy. Also, a household where the head of the household attained a lower level of education was found to use less energy. Appliance factors such as the presence of a tumble dryer and a dishwasher both result in more energy usage.

After reviewing the literature, the direction of the relationship of the main determinants of household energy consumption/demand in global studies is still open to debate, whereas for Ireland the evidence is much clearer. Generally urban privately owned households use more energy as compared with rented or rural households. A head of a household who has attained a lower level of education uses less energy than those with third-level degrees. Also newly constructed housing units and apartments use less energy. However, none of the Irish studies[6] examined whether the presence of a micro-RES would reduce energy usage, and what household determinants result in ownership of a micro-RES.

[6] Leahy and Lyons (2010) included the variable renewable source for water heating only and no other forms of renewable used for electricity whereas this study accounts for both.

III METHODOLOGY

3.1 Data

This paper uses anonymised microdata collected from the Irish Household Budget Survey (HBS) 2010.[7] The HBS is a survey of a representative random sample of all private households in Ireland. Surveys have been carried out periodically in Ireland since 1951 and generally every five years since 1994. The 2009-2010 HBS was undertaken between the months of August 2009 to September 2010 and covered 5,891 households.

The following socio-economic variables were included in our study arising from the literature reviewed: number of persons living in household; average weekly disposable household income; family composition (whether a home has children or not); highest completed level of education of chief economic supporter (CES); and household tenure (owned or rented). Dwelling characteristic variables are as follows; year accommodation was built, number of bedrooms, and location of house (urban or rural). Appliance variables include; dishwasher, tumble dyer, fridge-freezer, microwave, games console, and number of televisions.

The HBS questionnaire survey does not ask what type of micro-RES has been installed in the dwelling outright. However, through several energy questions asked in the survey about the dwelling, a dummy variable was constructed to represent households with a micro-RES installed. These energy questions included what type of central heating system is used for space heating in the winter[8] where renewable source is a selectable answer. The other question relates to the method of water heating in the winter, where source is a selectable answer. If a household answered renewable for any of these questions it was given the value of 1 under our variable micro-RES and conversely a value of zero when it is not.

As noted by Leahy and Lyons (2010) the HBS does not do enough to address every aspect of household energy use. It lacks extensive information on several issues especially energy efficiency of dwellings and the frequency of appliances and heating usage. However, the HBS does report on the average weekly expenditure on energy by fuel; namely electricity expense, natural gas expense, liquid fuel expense, solid fuel expense and total weekly expense on all fuels. Using the same method as Leahy and Lyons (2010), in order to evaluate the average household energy use by total fuel use and only electricity, the following formula was employed. The estimated energy use from electricity measured in kilowatt hours was constructed using the following equation;

$$elecuse_i = (expenditure_i^{elec}/price^{elec})(kWh^{elec}/q^{elec}) \quad (1)$$

[7] This household survey being a number of years old is nevertheless the most up to date available in micro-RES installations. While a newer study was published in 2016, it did not contain the necessary data on micro-RES as the relevant question was dropped from the survey.

[8] The survey does not address the same question for any season other than winter.

where $expenditure_i^{elec}$ is the average weekly expenditure by household i on electricity. $Price^{elec}$ is the average unit price of electricity for the period in which the household was interviewed. Price data were obtained from SEAI (Appendix A). kWh^{elec}/q^{elec} is the kw/h of electricity per unit and is known as the gross calorific value; for electricity this is 1. Similarly, for each form of the remaining fuels (natural gas, liquid heating oil and solid fuel) the corresponding value for average weekly expenditure, price data and gross calorific value are input.

3.2 Micro-Res Ownership Model

The objective of the first part of this paper is to establish a profile of the average house that adopts micro-RES and we constructed a Logit model for this purpose (Braun, 2010). We use a step-wise depletion method of variables in order to estimate a leaner model which omits explanatory variables that are not significant (Leahy and Lyons, 2010). This model included many of the socio-economic, dwelling and appliance variables set out by the literature that are significant in determining household energy use.

3.3 Energy Consumption Model

The second part of the analysis into micro-RES investigates whether it has had an impact on the average weekly household energy use by fuel type. A log-linear model based on ordinary least squares (OLS) method will be used. Two models will be used, one with the dependent variable being total fuel use and the other with the dependent variable being electricity use. The models can be formulated using the following Equation (2);

$$lneregyuse = \beta_0 + \Sigma_i \beta_i X_i + \varepsilon_i \tag{2}$$

where *energyuse* indicates the average energy use by fuel type, X is a list of predicator variables and ε_i is the unobserved error term. Again, previous literature directed the choosing of variables used for modelling household energy use (Druckman and Jackson, 2008; McLoughlin *et al*., 2012; Wiesmann *et al*., 2011; Zhou and Teng, 2013).

IV RESULTS

4.1 Logit Model

Results from the Logit model are presented in Table 2. Results reveal that households with higher weekly disposable income are more likely to have access to micro-RES. This is not surprising since micro-RES installations are very expensive and support schemes are not as favourable in comparison to other EU countries, which results in longer payback period for Irish customers. Households

in urban areas are less likely to avail of micro-RES than their rural counterpart. This may be a result the density of houses in urban areas and restrictive building regulations for some types of micro-RES, particularly micro wind turbines. If the household is owned by the occupant they are more likely to have micro-RES than those who rent their property. It stands to reason that an owner-occupier is more willing to invest in the property than a renter.

The level of education acquired by the chief economic supporter (CES) also plays a role in whether a household is likely to adopt micro-RES. Households where the CES has only acquired a primary school level of education or has no formal education are less likely than those CES in the reference category who acquired education at a third-level institution to have adopted micro-RES. If the CES has attained an education at third-level institution it would be understandable that, first, they would have a career where they earned a larger salary in relation to the CES of the other categories, which would result in a greater ability to purchase micro-RES. Second, if the CES attained an education at a third-level institution they may have a greater awareness of environmental issues and the benefits of micro-RES.

The results from the house construction year categorical variable are all statistically significant, bar houses constructed pre-1918, and have a negative sign in relation to the reference category of houses built in the period 2006-2010. Inferring for example that for the variable 1918-1945, houses built during this time are less likely than those houses built between 2006-2010 to have adopted micro-RES. It should also be noted that the size of the coefficient does not increase linearly in the house construction year variables. We attribute this to higher installation costs when retrofitting an older house with micro-RES.

Table 2: Logit Regression Results for the Determinants of Micro-RES Installation (Results are Presented as Odds Ratios)

	Coef.
Log of Household Disposable Income	0.4836**
Number of People	0.0018
Urban and Rural Household Location	–1.0766***
Ownership or Rental Household	2.0533***
Household with Children	0.4893**
Education Status of CES	
Primary School, No Formal Education, Other	–1.0794**
Secondary School	–0.4701**
Higher Institute	(R.C.)
House Construction Year	
Pre-1918	–0.5795
1918-1945	–1.1769**
1946-1960	–1.8636**

Table 2: Logit Regression Results for the Determinants of Micro-RES Installation (Results are Presented as Odds Ratios) (Contd.)

	Coef.
1961-1970	–1.2947**
1971-1980	–1.3410***
1981-1990	–2.5067***
1991-2000	–0.9924***
2001-2005	–1.3800***
2006-2010	(R.C.)
Number of Bedrooms	0.315***
Constant	–8.7955***
No of Observations	5,818
R^2	0.172

Source: Authors' analysis.
Notes: * significant at the 10 per cent level, ** Significant at the 5 per cent level, *** Significant at the 1 per cent level, R.C. Reference Category.

4.2 OLS Regression

Energy use was modelled by total fuel use (Model 1) and electricity use (Model 2). As well as our main variable of interest, micro-RES, we studied the influence of several household characteristics; socio-economic, dwelling and appliance factors. The dependent variable was energy use which was broken down into further sub-categories of electricity use, natural gas use, liquid fuel use, solid fuel use and total fuel use. Using ordinary least squares (OLS), the estimated regression coefficients are presented in Table 3.

First, the presence of micro-RES was only statistically significant for electricity use, where the presence of micro-RES resulted in more electricity use compared to households without micro-RES. The cause of this may be a result of the rebound effect where improved energy efficiency gives rise to a reduction in energy prices; however lower prices will increase energy consumption to some extent (Wang *et al.* 2014). More specifically, this may be the income effect as a result of the direct rebound effect;

> when improvement in energy efficiency reduces the cost of a particular goods or services, consumers need to spend less to get the same outcome as before. Thus an increase in real income allows to achieve higher utility by increasing consumption of the same goods or services, including the energy service (Labidi and Abdessalem, 2018, p. 11).

Results across the socio-economic variables were in line with the previous literature. A larger number of people living in a household results in greater energy use, both for total overall fuel as well as for electricity use. As expected a higher weekly

Table 3: OLS Regression Results for the Determinants of Total Overall Fuel Use and Electricity Use

	Model 1 Total Fuel Use Coef.	*Model 2 Electricity Use Coef.*
Renewable Energy System	–0.021	0.202***
Number of People in Home	0.057***	0.113***
Log of Household Disposable Income	0.082***	0.063***
Urban and Rural Household Location	–0.048	–0.043
Ownership or Rental Household	0.104	–0.014
Household With or Without Children	0.098***	0.058*
Education Status of CES		
Primary School, No Formal Education, Other	(R.C)	–0.122**
Secondary School	–0.007	0.001
Higher Institute	–0.030	(R.C.)
House Construction Year		
Pre-1918	0.094*	0.012
1918-1945	0.242***	–0.087
1946-1960	0.274***	–0.133
1961-1970	0.148*	–0.159*
1971-1980	0.162**	–0.026
1981-1990	0.139	–0.058
1991-2000	-0.021	–0.04
2001-2005	–0.016	–0.053
2006-2010	(R.C)	(R.C.)
Number of Bedrooms	0.129***	0.061***
Appliances		
Dishwasher	0.115***	0.172***
Tumble dryer	0.008	0.04**
Fridge-freezer	0.063**	–0.017
Microwave	0.085*	0.027
Console	0.040	0.056**
Number of TVs	0.044***	0.030***
Constant	4.419***	3.049***
Inverse Mills Ratio	–0.052	0.137
R^2	0.184	0.210
F-stat	53.97***	50.83***
No of Observations	5,759	4,607

Source: Authors' analysis.

Notes: * significant at the 10 per cent level, ** Significant at the 5 per cent level, *** Significant at the 1 per cent level, R.C. Reference Category.

disposable income results in an increased energy use for total overall fuels and electricity use. A household with children uses more energy overall, and electricity, when compared to a household without children. In terms of education, it was found to only be significant in the case of electricity use where a CES with a primary school education or no formal education uses less than the reference category.

Results from the dwelling factors show that having an extra bedroom in a house will increase total overall fuel as well as electricity use which is in line with the literature. When investigating the variable year of house construction the reference category varies across each model. In general, the more recently constructed households use less energy than that of the reference categories.

To summarise, the results strongly support the finding that newer built homes use less fuel than older homes, indicating that Irish policy to increase energy efficiency in the residential sector through greater efficiency standards is having its desired impact.

Results from appliance factors affecting energy use in a household varied across all the models. Households that had access to a dishwasher were found to be statistically significant in terms of increasing total overall fuel and electricity use. Households that had access to a tumble dryer were found to use more electricity while, in terms of solid fuel use, households with a tumble dryer use less. Households that had access to a fridge-freezer were found to be statistically significant in terms of increasing total overall fuel and natural gas use. Households that had a larger number of televisions were found to be statistically significant in terms of increasing total overall fuel, electricity, natural gas and liquid fuel use.

The results of our study support the finding that households that have adopted micro-RES are more likely to be wealthier households, taking advantage of support schemes designed to financially incentivise households that are tentative about the decision whether or not to adopt micro-RES. As these schemes are funded through consumer energy bills, this may relatively disadvantage poorer households. Given our findings that the presence of micro-RES does not result in a decrease in total energy use in the home, we suggest that this element of Irish energy policy around residential sector needs to be re-evaluated. While the promotion of micro-RES is an essential element as part of our energy policy goals, there is also a need to inform adopters to change their "behaviour as usual" approach to address the rebound effect.

The inverse Mills ratio variable was included in the regression to test for sample selection bias. In both models – total fuel use and electricity use – the inverse Mills ratio variable was statistically insignificant meaning that there is no sample selection bias (Heckman, 1979).

V CONCLUSION

Micro-RES, properly supported, could have the potential to significantly contribute towards Ireland's climate change goals. Governments worldwide have recognised this by implementing strategies to stimulate the growth of micro-RES at the residential level. In Ireland, electrical micro-RES growth has been relatively slow which may be partially attributable to ineffective governmental support mechanisms as compared with other countries.

In this paper, we investigated firstly the determinants of household ownership of a micro-RES using a Logit regression and secondly whether the presence of such would result in a decrease in energy demand by using an ordinary least squares regression. Analysis was carried out on the Irish Household Budget Survey dataset.

Although there are some financial incentives provided to Irish residents to adopt micro-RES, it would seem that these schemes are mainly availed of by wealthier households. As results attained from our Logit model show, the average household that is most likely to adopt micro-RES is a large[9] house that has been constructed recently and is owner-occupied. The owner is most likely to be highly educated and is wealthy. The results would suggest that the households adopting micro-RES and availing of the support schemes are the ones that need them the least and that, for many, installing a micro-RES is still a luxury purchase in Ireland. However, some of Ireland's energy policies seem to be working; improvements in housing energy efficiency standards has resulted in newly constructed houses using less energy than older houses.

The second part of this study was to find the determinants of household energy use and whether micro-RES has had an impact on reducing energy use. It was found that the determinants of household energy consumption were in line with those of previous literature. Surprisingly, it was found that the presence of micro-RES was only statistically significant in the electricity use model, where the presence of micro-RES increased electricity use.

Ireland is one of eight EU Member States with a renewable energy share that was below the anticipated trajectories as laid out in the NREAPs.[10] While Irish energy policy papers continue to address the importance of Irish citizens in combatting climate change and meeting their environmental goals through the promotion of energy saving appliances and micro-RES, results from this analysis would suggest that these policies need adjustment (EEA, 2017).

[9] Large number of bedrooms.
[10] National Renewable Energy Action Plan (2015).

REFERENCES

Allen, S. R., G. P. Hammond and M. C. McManus, 2008. "Prospects for and Barriers to Domestic Micro-Generation: A United Kingdom perspective", *Applied Energy*, Vol. 85, No. 6, pp. 528-544.

Baker, K. J. and R. M. Rylatt, 2008. "Improving the Prediction of UK Domestic Energy-Demand Using Annual Consumption-Data", *Applied Energy*, Vol. 85, No. 6, pp. 475-482.

Bartiaux, F. and K. Gram-Hanssen, 2005. "Socio-political Factors Influencing Household Electricity Consumption: A Comparison Between Denmark and Belgium", Paper presented at the ECEEE 2005 Summer Study, European Council for an Energy Efficient Economy.

Bartusch, C., M. Odlare, F. Wallin and L. Wester, 2012. "Exploring Variance In Residential Electricity Consumption: Household Features and Building Properties", *Applied Energy*, Vol. 92, pp. 637-643.

Bedir, M., E. Hasselaar and L. Itard, 2013. "Determinants of Electricity Consumption in Dutch Dwellings", *Energy and Buildings*, Vol. 58, pp. 194-207.

Belaid, F., 2016. "Understanding the Spectrum of Domestic Energy Consumption: Empirical Evidence from France", *Energy Policy*, Vol. 92, pp. 220-233.

Braun, F. G., 2010. "Determinants of Households' Space Heating Type: A Discrete Choice Analysis For German Households", *Energy Policy*, Vol. 38, No. 10, pp. 5493-5503.

Brounen, D., N. Kok and J. M. Quigley, 2012. "Residential Energy Use and Conservation: Economics and Demographics", *European Economic Review*, Vol. 56, No. 5, pp. 931-945.

Carter, A., R. Craigwell and W. Moore, 2012. "Price Reform and Household Demand for Electricity", *Journal of Policy Modeling*, Vol. 34, No. 2, pp. 242-252.

Chong, H., 2012. "Building Vintage and Electricity Use: Old Homes Use Less Electricity in Hot Weather", *European Economic Review*, Vol. 56, No. 5, pp. 906-930.

Copiello, S. and L. Gabrielli, 2017. "Analysis of Building Energy Consumption Through Panel Data: The Role Played by the Economic Drivers", *Energy and Buildings*, Vol. 145, pp. 130-143.

Cramer, J. C., N. Miller, P. Craig, B. M. Hackett, T. M. Dietz, E. L. Vine *et al*., 1985. "Social and Engineering Determinants and Their Equity Implications in Residential Electricity Use", *Energy,* Vol. 10, No. 12, pp. 1283-1291.

Druckman, A. and T. Jackson, 2008. Household Energy Consumption in the UK: A Highly Geographically and Socio-Economically Disaggregated Model, *Energy Policy*, Vol. 36, No. 8, pp. 3177-3192.

EEA, 2017. *Trends and Projections in Europe 2017. Tracking Progress Towards Europe's Climate and Energy Targets* Luxembourg, https://www.eea.europa.eu/publications/trends-and-projections-in-europe-2017: Publications Office of the European Union.

Gram-Hanssen, K., C. Kofod and K. Petersen, 2004. "Different Everyday Lives: Different Patterns of Electricity Use". Paper presented at the ACEEE 2004 Summer Study, American Council for an Energy Efficient Economy.

Harold, J., J. Cullinan and S. Lyons, 2017. "The Income Elasticity of Household Energy Demand: A Quantile Regression Analysis", *Applied Economics*, pp. 1-9.

Harold, J., S. Lyons and J. Cullinan, 2015. "The Determinants of Residential Gas Demand in Ireland", *Energy Economics*, Vol. 51, pp. 475-483.

Heckman, J. J., 1979. "Sample Selection Bias as a Specification Error", *Econometrica*, Vol. 47, No. 1, pp. 153-161.

Huebner, G., D. Shipworth, I. Hamilton, Z. Chalabi and T. Oreszczyn, 2016. "Understanding Electricity Consumption: A Comparative Contribution of Building Factors, Socio-Demographics, Appliances, Behaviours and Attitudes", *Applied Energy*, Vol. 177, pp. 692-702.

Islam, T., 2014. "Household Level Innovation Diffusion Model of Photo-Voltaic (Pv) Solar Cells From Stated Preference Data", Energy Policy, Vol. 65, pp. 340-350.

Iwafune, Y. and Y. Yagita, 2016. "High-resolution Determinant Analysis of Japanese Residential Electricity Consumption Using Home Energy Management System Data", *Energy and Buildings*, Vol. 116, pp. 274-284.

Jones, R. V., A. Fuertes and K. J. Lomas, 2015. "The Socio-Economic, Dwelling and Appliance Related Factors Affecting Electricity Consumption in Domestic Buildings", *Renewable and Sustainable Energy Reviews*, Vol. 43, pp. 901-917.

Labidi, E. and T. Abdessalem, 2018. "An Econometric Analysis of the Household Direct Rebound Effects fFor Electricity Consumption in Tunisia", *Energy Strategy Reviews*, Vol. 19, pp. 7-18.

Larsen, B. M. and R. Nesbakken, 2004. "Household Electricity End-Use Consumption: Results From Econometric and Engineering Models", *Energy Economics*, Vol. 26, No. 2, pp. 179-200.

Leahy, E. and S. Lyons, 2010. "Energy Use and Appliance Ownership in Ireland", *Energy Policy*, Vol. 38, No. 8, pp. 4265-4279.

Matsumoto, S., 2016. "How Do Household Characteristics Affect Appliance Usage? Application of Conditional Demand Analysis To Japanese Household Data", *Energy Policy*, Vol. 94, pp. 214-223.

McCoy, D. and J. Curtis, 2018. "Exploring the Spatial and Temporal Determinants of Gas Central Heating Adoption", *Resource and Energy Economics, Vol.* 52, pp. 64-86.

McLoughlin, F., A. Duffy and M. Conlon, 2012. "Characterising Domestic Electricity Consumption Patterns By Dwelling and Occupant Socio-Economic Variables: An Irish Case Study", *Energy and Buildings*, Vol. 48, pp. 240-248.

Michelsen, C. C. and R. Madlener, 2016. "Switching From Fossil Fuel to Renewables in Residential Heating Systems: An Empirical Study of Homeowners' Decisions in Germany", *Energy Policy*, Vol. 89, pp. 95-105.

Mills, B. F. and J. Schleich, 2009. "Profits or Preferences? Assessing The Adoption oOf Residential Solar Thermal Technologies", *Energy Policy*, Vol. 37, No. 10, pp. 4145-4154.

SEAI, 2017. Home Grants. Retrieved 12/10/2018, 2018

Sopha, B. M., C. A. Klockner, G. Skjevrak and E. G. Hertwich, 2010. "Norwegian Households' Perception of Wood Pellet Stove Compared to Air-to-Air Heat Pump and Electric Heating", *Energy Policy*, Vol. 38, No. 7, pp. 3744-3754.

Tso, G. K. F. and K. K. W. Yau, 2007. "Predicting Electricity Energy Consumption: A Comparison of Regression Analysis, Decision Tree and Neural Networks", *Energy*, Vol. 32, No. 9, pp. 1761-1768.

Wallis, H., M. Nachreiner and E. Matthies, 2016. "Adolescents and Electricity Consumption; Investigating Sociodemographic, Economic, and Behavioural Influences on Electricity Consumption in Households", *Energy Policy*, Vol. 94, pp. 224-234.

Wang, Z. H., M. L. Lu and J. C. Wang, 2014. "Direct Rebound Effect on Urban Residential Electricity Use: An Empirical Study in China", *Renewable and Sustainable Energy Reviews*, Vol. 30, pp. 124-132.

Wiesmann, D., I. L. Azevedo, P. Ferrao and J. E. Fernandez, 2011. "Residential Electricity Consumption in Portugal: Findings fFrom Top-Down and Bottom-Up Models", *Energy Policy,* Vol. 39, No. 5, pp. 2772-2779.

Zhou, S. J. and F. Teng, 2013. "Estimation of Urban Residential Electricity Demand in China Using Household Survey Data", *Energy Policy*, Vol. 61, pp. 394-402.

APPENDIX A

Gross Calorific value (kW h/unit) by fuel type. Quarterly average fuel price per unit.

Fuel Type	*Gross Calorific Value*	*Price*				
		Q3 2009	*Q4 2009*	*Q1 2010*	*Q2 2010*	*Q3 2010*
Heating Oil	10.6	0.66	0.63	0.70	0.76	0.86
Gas	1	0.06	0.05	0.05	0.05	0.05
Electricity	1	0.17	0.15	0.15	0.15	0.15
Wood	4.8	0.22	0.22	0.22	0.22	0.22

APPENDIX B

Descriptive Statistics

Variable	*Mean*	*Standard Deviation*
Electricity Use (Estimated energy use from electricity kw/h)	15.82	11.00
Total Fuel Use (Estimated energy use from total fuel kw/h)	34.49	23.99
Disposable Income (€ weekly)	905.31	674.18
Number of Persons	2.72	1.49
Number of Bedrooms	3.22	1.05
Number of TVs	2.20	1.33

Variable	*Mean*	*Variable*	*Mean*
Children In household		*Location of household*	
Children	30.5%	Urban	68.0%
No Children	69.5%	Rural	32.0%
Ownership status of household		*Appliance Ownership*	
Own	68.5%	Micro Renewable Energy Systems	1.5%
Rent	31.5%	Dishwasher	64.1%
Education level attained by CES		Tumble Dryer	66.6%
Primary Level Education	21.3%	Fridge Freezer	81.2%
Secondary Level Education	31.9%	Microwave	91.4%
Third-level Education	46.8%	Console	39.9%

Period in which accommodation was built	
Pre-1918	8.5%
1918-1945	7.8%
1946-1960	7.3%
1961-1970	6.0%
1971-1980	12.5%
1981-1990	9.6%
1991-2000	14.7%
2001-2005	20.0%
2006-2010	13.6%