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Report on the impact of energy literacy on the level of energy efficiency

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Empirical estimation of the level of energy efficiency in the European household sector: evidence from Italy, the Netherland and Switzerland

Abstract

In this report, we analyse the level of energy efficiency in the use of electricity in the European residential sector using a cross-sectional dataset comprised of 1620 observations from Italian, Dutch and Swiss households observed in 2016. To do this, we estimate an electricity demand frontier function using a stochastic frontier approach. The demand frontier function reflects the minimum electricity needed to produce a predefined level of energy services. This benchmarking analysis estimates an efficiency index for each household.

The empirical results show that the residential sector in these three European countries could save approximately 25-30% of its total electricity consumption on average if it improves the level of efficiency in the use of electricity. These figures are in line with recent studies for Switzerland and for the US residential sector.

JEL Classification: D, D2, Q, Q4, Q5.

Keywords: European residential electricity demand; energy demand frontier function Household data.

1. Introduction

EU countries agreed on a 2030 framework for climate and energy, which sets new and challenging targets for the European Union post-2020 low carbon framework. Among the targets, there is the binding commitment to improve energy efficiency by at least 27% for the year 2030, compared to projections of future energy consumption based on the current criteria. Lately, the Commission even increased the energy efficiency target for 2030 to 30% within the new Energy Efficiency Directive. Improvements in energy efficiency represent a crucial strategy to meet the long-term 2050 greenhouse gas reductions target. Moreover, energy saving through investments in energy efficiency is crucially important, as it contributes to achieve a more competitive, secure and sustainable energy system, and it is an important means to save money. In 2016 for example, households across the world saved 10 to 30% of their annual energy spending because of energy efficiency gains (IEA, 2017a).

Technological change and innovations are important drivers of energy efficiency. Nowadays, new technology is available at a low cost. To improve the adoption of new energy efficient technologies, regulatory approaches such as codes and standards have been extensively adopted. However, big challenges remain in the process to achieve the energy efficiency target. Firstly, at the moment mandatory codes and standards have been adopted to cover only one-third of global energy use, implying that two third of global final energy use remains uncovered by policies (IEA, 2017a). Secondly, energy efficiency depends not only on the availability of cheap technologies or policy interventions but is also largely influenced by individual-specific behaviour. Although some consumers are aware that improvements in efficiency provides the dual opportunity to reduce energy cost and negative externalities that energy use brings, they often fail to consume energy efficiently by the fact that they do not adopt energy efficient appliances or do not use their appliances in an optimal way. For instance, a household might postpone substituting an old and inefficient refrigerator that consumes a lot of electricity or does not use a cooling system or washing machine in the most efficient way.

The potential explanations for an inefficient use of appliances on the one hand, and for an under-investment in energy-efficient appliances on the other hand can be attributed to a multitude of barriers. Schleich et al. (2016) distinguish between external and internal barriers. External barriers are typically factors external to the agents that mainly depend on institutional settings. These barriers can take the form of (1) capital market failures, such as liquidity constraints, and (2)

information problems, such as lack of information on product availability and energy efficient attributes. Not only lack of information, but also asymmetric information combined with split incentives between a principal (for example the landlord) and an agent (tenant) prevents investments in energy-efficient appliances. Finally, financial and technological risks may represent a third external barrier to energy efficiency.

However, even if these market failures could be overcome, other barriers that have to do with factors that relate to individual preferences and behaviour exist. These barriers are labelled internal in the taxonomy provided by Schleich et al. (2016). Time, risk and environmental preferences, along with loss aversion and risk aversion (due to reference-dependence and non-linear probability weighting), rational inattention, present-bias, myopia and status-quo bias potentially reduce the level of efficiency in a household's energy use. As discussed in Blasch et al. (2017b), another possible reason for people not to see and pick up the low-hanging benefits of energy efficiency is associated with bounded rationality. In order to choose between two appliances with the same functionality, a rational, utility-maximizing consumer should choose the one that minimises lifetime cost (i.e. the sum of purchase price and future energy costs). However, specific forms of literacy are needed to perform this optimisation. An optimal decision from an economic point of view requires both specific knowledge (e.g. of the purchase prices of the two appliances, their electricity consumption, their expected lifetime, the expected intensity and/or frequency of use, as well as current and future electricity prices) and specific cognitive skills, which include the ability to calculate the lifetime cost of the two appliances. However, the theory of "bounded rationality" postulates that most individuals have limited capacities to process information and therefore often fail to make optimal decisions based on rational calculations. Instead, many individuals use simple rules of thumb when making their choices. Blasch et al. (2017b) report a correlation between energy and investment literacy and bounded rational behaviour.[1]

Given the energy efficiency target described above, it is important for policy makers to have an estimate of the potential electricity saving in households. Moreover, it is crucial to know the determinants of the level of efficiency in the use of electricity, and the role of some of the barriers

[1] In the description of this task we used the term "*energy and investment literacy*". However, due to development in our research (see Blasch et al. (2018)) we changed this term in this report to "*energy-related financial literacy*". Following Blasch et al. (2018), energy-related financial literacy is the level of energy-related knowledge and cognitive abilities that consumers need to have in order to take investment decisions related to energy consumption. So far, the academic literature has not developed a common concept of literacy in the context of energy-related investment decision making in the residential sector. For more details see Blasch et al. (2018).

listed above. While the implications on energy efficiency of external barriers are well documented, internal barriers and their impact on energy efficiency are less studied and less so the effect of bounded rationality. In this report, using survey data from three European countries, we aim to address these issues. In particular, using appropriate econometric techniques, we answer the following questions: What is the level of efficiency in the use of electricity of European households?[2] How large is the potential for electricity savings in the residential sector for a given level of energy services? Which are the factors that influence the electricity demand at the household level and in particular, what is the role of energy-related financial literacy? To do so, we propose to use a concept of "energy-related financial literacy" introduced by Blasch et al. (2018) that combines both, the energy-relevant knowledge and the skills to perform an investment calculation, that households need to take informed decisions with respect to energy consumption.

One possible way to evaluate energy efficiency of households is through ex ante engineering estimates, based on bottom-up models. These models require detailed information about the relative efficiency of various types of energy-using equipment, information of the existing deployment, and assumptions about usage patterns. However, these models have limitations. For example they ignore complex interactions, make erroneous assumptions about usage, face quality control problems but most importantly they do not take into account individual behaviour (Gerarden et al., 2017). Ex post evaluations, which use actual energy usage, represent a better approach to measure energy efficiency and potential energy savings. In this report, we apply this second approach and estimate an electricity demand frontier function using a stochastic frontier analysis based on econometric methods. This frontier can be interpreted as the minimum level of electricity that a household needs, in order to obtain a certain level of energy services. The divergence between actual and the cost-minimizing consumption obtained from the frontier can be treated as inefficiency. To compute this measure, we use information on the observed electricity use.

The contribution of this report is twofold. First, we estimate energy efficiency through a stochastic frontier analysis using disaggregated data from three different European countries. This is the first study that is able to collect micro level data on electricity use, energy service and other household

[2] The residential sector accounts for around one fourth of final energy consumption and for around 53% of global electricity demand (IEA, 2017b). Initially, we wanted to estimate the level of efficiency in the use of all sources of energy at the household level. However, due to the difficulty to collect information on gas and oil consumption we decided to focus on the analysis of the electricity consumption. Of course, we are aware that this is a limitation. Anyway, we think that given the important role of electricity in the energy strategy our study makes a contribution.

level information in different European countries and apply them in a stochastic frontier analysis. The second contribution is that this report is one of the few studies that links electricity consumption to energy-related financial literacy. This report informs on the effect of energy-related financial literacy, which is correlated to bounded rationality, on the level of electricity consumption through the electricity demand frontier.

The rest of this this report is organised as follows. In the next section, we provide an overview of the literature. In Section 3 we develop a model for the estimation of the level of efficiency in the use of electricity in European households. In Section 4 we describe the household survey data. The results we present in Section 5. In the final section we offer concluding remarks.

2. Review of the literature

Our work is related to two strands of literature. The first is the literature on energy efficiency which uses stochastic frontier methods. Stochastic frontiers have been originally applied to analyse economy-wide energy efficiency using aggregate energy consumption data for the whole economy. Filippini & Hunt (2011) model energy efficiency for an unbalanced panel of 29 OECD countries from 1978 to 2006, controlling for income, price, population and weather variables that affect energy demand. Zhou et al. (2012) use cross-section data for 21 OECD countries. Lin & Du (2013) examine the efficient use of energy for 30 Chinese administrative regions from 1997 to 2010.

Other papers applied aggregated data to study energy efficiency but with a focus on the residential sector. Filippini & Hunt (2012) use residential aggregate energy consumption for 48 US states over the period 1995 to 2007. Otsuka (2017) analyse residential electricity energy efficiency using data from 47 prefectures in Japan from 1990 to 2010. Filippini et al. (2014) utilize data for 27 EU member states for the period 1996 to 2009 and assess the contribution of energy efficiency policies on energy efficiency improvements in the residential sector. The paper finds that while financial incentives and energy performance standards promote energy efficiency, informative measures such as labelling and educational campaigns are less effective.

More recent papers were able to circumvent the data limitation of early analyses and apply stochastic frontier analysis to the residential sector using disaggregated data at the household level. Weyman-Jones et al. (2015) use cross-section survey data to analyse the level of efficiency in the use of electricity in Portuguese households. Broadstock et al. (2016) estimate stochastic electricity demand frontier functions for a cross-section sample of more than 7000 Chinese

households. Similarly, Boogen (2017) estimates the level of efficiency in the use of electricity in Swiss households using cross-sectional data of two survey waves in 2005 and 2011.

Additional advances are provided in Alberini & Filippini (2018). The authors were able to assemble a large panel dataset for US households from 1997 to 2009. Applying panel data, the authors can decompose the level of energy efficiency into a persistent and a transient component. The persistent part is due to the presence of structural problems or systematic behavioural failures. The transient part, on the contrary, can be solved in the short term as it is mainly due to the presence of non-systematic minimisation problems. The authors use a novel econometric approach which was originally applied by Filippini & Greene (2016) to study productive efficiency of railway companies.

A second strand of literature on the effect of bounded rationality on some measures of energy efficiency can be relevant to our report. There are limits in human capacity to process and evaluate information. Therefore in complex situations people rely on a simple counting heuristic and rules of thumb that help simplifying the decision-making process. Camilleri & Larrick (2014) provides evidence of the link between bounded rationality and energy efficiency. They find that information on fuel consumption rather than fuel costs and the use of a more comprehensive mileage scale increase preferences towards fuel efficient vehicles. Given bounded rationality, the decision making is less effortful if the problem representation matches the problem-solving processes. Ungemach et al. (2017) confirm that people often apply simple heuristics when choosing between cars and they are influenced by highly correlated attributes, rather than their meaning. Providing multiple translations of energy efficiency metrics could help guiding behaviour in favour of energy efficient choices.

Some papers study the impact of energy and investment literacy on energy efficiency. Brounen et al. (2013) find that energy literacy is low among a survey of 1,721 Dutch households. However they also find that energy literacy and awareness are unrelated to energy consumption and conservation behaviour. Blasch et al. (2017a) is the paper that most closely relates to the present analysis. The paper follows the energy demand frontier approach using household level data in Switzerland from 2010 to 2014. Moreover, it provides a systematic analysis of the effect of energy and investment literacy on efficiency in residential electricity consumption. The paper finds lower energy inefficiency among households scoring high in terms of energy and investment literacy.

3. A model of electricity demand

For the specification of electricity demand, we should keep in mind that residential electricity consumption is driven by the demand for energy services such as lighting, cooked food, washed clothes, hot water. For the production of these energy services a household combines two inputs, i.e. electricity and capital (fridges, washing machines, electronics, light bulbs, cooling systems, etc.). In this context, a household has to identify the optimal input demand for capital and electricity that minimises the cost to produce a predefined level of energy services, which, as suggested by the household production theory, are included in the household's utility function (Alberini & Filippini, 2011).

In case a household is not using the optimal amount of electricity or capital to produce a predefined level of energy services, the production process is characterized by inefficiency in the use of both or one of these inputs.[3]

A simple and intuitive way to present the concept of energy inefficiency is to use a figure that illustrates the relation between electricity consumption and the level of energy services. For instance, Figure 1 presents a situation of a household that, for the production of the level of energy service (ES_0), is using the quantity of electricity (E_{obs}) instead of using the optimal quantity of electricity (E_{fro}) defined by the electricity demand frontier function. This frontier function defines the minimum amount of electricity required to produce a predefined level of energy services, given the level of technology, input prices and other factors. Therefore, a household that is not using the minimum quantity of electricity as defined by the frontier is characterised by inefficiency in the use of electricity. The ratio between the optimal and the observed use of electricity needed to produce an energy service is defined as the level of energy efficiency of a household. If this ratio is equal one, then the level of energy efficiency is 100%; if the ratio is lower than one, then the household shows a lower level of efficiency, which means inefficiency in the use of electricity.

[3] Filippini & Hunt (2015) present a detailed theoretical discussion of the concept of energy efficiency based on the microeconomics theory of production.

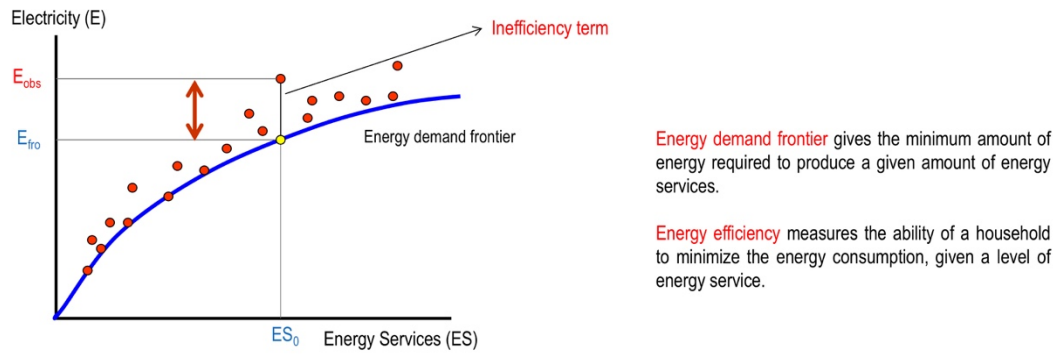

Figure 1: Estimation of an energy demand frontier model.

In order to estimate the level of energy efficiency of an economic unit, in our case a household, Filippini & Hunt (2011) propose to estimate an energy demand frontier function using econometric methods. In this report we decided to follow this approach.[4]

In our econometric analysis based on micro-level data from Italian, Dutch and Swiss households, we initially defined the following general household electricity demand function:

$$E_i = f(P_i^E, P_i^C, Y_i, X_i, ES_i, EFL_i, EF_i) \quad (1)$$

where E_i is the electricity consumption of household *i*, P_i^E is the price of electricity, P_i^C is the price of capital (i.e., the price of appliances and/or heating and cooling equipment), Y_i is income, X_i is a vector of house and household characteristics, ES_i is a vector of energy services consumed by a household, EFL_i represents an indicator of the level of energy-related financial literacy and EF_i is the level of energy efficiency.

Unfortunately, due to missing information for part of the households, we were forced to omit the electricity price and the capital price in Equation (1). In order to consider, at least partially, the differences in the prices among the utilities, we introduced utility specific dummies. Of course, we are aware that these dummy variables are capturing also other institutional and regional differences that influence electricity demand.

In the empirical specification, vector X includes the square meters of the dwelling, household size, and the age of the home. It also includes information on the presence of large and energy-intensive

[4] From a methodological point of view there are three main approaches that can be used to estimate the level of energy efficiency (the input requirement function, and the energy demand frontier function and the sub-vector input distance function (also called Shepard input distance function)). For a presentation of these approaches see Filippini & Hunt (2015).

appliances such as freezers, saunas, or electricity-based space and water heating systems. Furthermore, following Blasch et al. (2017a), in the model we control for the number of light bulbs and energy services consumed such as the number of meals cooked on electric stoves, the number of washing and drying cycles, the number of dishwasher cycles as well as the number of TV and computer hours. Utility specific dummy indicators are also included in order to account for regional heterogeneity such as price differences. Education is captured through a dummy variable that specifies whether a subject went to university or not.

As mentioned in the introduction of this report, one of the goals of this study is to analyse the impact of households' level of energy-related financial literacy on electricity consumption.[5] Blasch et al. (2018) define this type of literacy as the level of knowledge and cognitive abilities consumers need to have in order to take informed investment and consumption decisions related to energy services. As discussed more specifically in Blasch et al. (2018) and in report D1.3 of the PENNY project, the questionnaire used in this project included eight questions on the level of energy-related financial literacy.[6]

Finally, Equation (1) includes the term EF, which is the unobserved level of electricity efficiency of the household that we want to estimate. From an econometric point of view, we decided to estimate EF using the stochastic frontier function approach (SFA) proposed by Aigner et al. (1977). This approach assumes that the level of inefficiency in the use of electricity can be represented by a one-sided non-negative term. Using a log-log functional form Equation (1) can be written as:

$$\ln E_i = \alpha + Z_i\beta + (v_i + u_i) \qquad (2)$$

where Z_i includes all explanatory variables mentioned above and the continuous variables are transformed into logs and the other variables are defined as before.

As usual in a stochastic frontier setting, the error term in Equation (2) is split in two independent parts. The first part, v_i, is a symmetric disturbance assumed to be normally distributed and capturing the random noise. The second part, u_i, is a one-sided measure of the level of energy

[5] In this empirical analysis the level of literacy of a household is approximated by the level of literacy of the respondent of the questionnaire.

[6] In the literature it is possible to find several papers analysing the impact of the level of financial literacy on several financial outcomes such as saving, retirement decisions and investment risk diversification. Generally, in these studies the definition of financial literacy introduced by Lusardi & Mitchell (2008) is used "Knowledge of basic financial concepts, such as the working of interest compounding, the difference between nominal and real values, and the basics of risk diversification". Further, the level of financial literacy is measured with three standard financial literacy questions on compound interest, inflation and risk diversification. These questions are also included in the eight questions used in the PENNY survey.

inefficiency that can follow different distributions depending on the assumptions taken. In our econometric analysis we assume that this term is a half-normally distributed.[7]

The level of efficiency in the use of electricity (EF) is then obtained:

$$\mathrm{EF_i} = \frac{\mathrm{E_i^F}}{\mathrm{E_i}} = \exp(-\hat{\mathrm{u}}_\mathrm{i}) \tag{3}$$

where E_i is the observed electricity consumption and E_i^F is the frontier demand of the ith household. A value of one of the index EF_i indicates that a household is 100% efficient. A value lower than one means that a household is inefficient, i.e. has a level of efficiency smaller than 100%.

4. Data

Our data come from a large-scale household survey, which has been conducted in four European countries (Germany, Italy, the Netherlands and Switzerland) within the PENNY project. The survey was implemented in collaboration with five national utility companies.[8] As the German data will only become available at a later stage, our analysis focuses on the remaining three countries.

4796 households participated in the survey in the three countries considered. Information on electricity and energy services consumption, dwelling characteristics and socio-economic attributes of the occupants were collected. Additionally, data on energy-related financial literacy as well as on other psychological and behavioural factors were obtained. Even though the survey gathered values of some variables for all the years 2012 to 2016, we only use the data for 2016 in the empirical analysis presented as there is missing information in the previous years. Unfortunately, some utility corporations participating in this project were not able to deliver the electricity consumption for the period 2012 to 2015. From an econometric point of view, we are not able to exploit the advantages of panel data for this reason. In particular, we cannot apply the recently

[7] The half-normal distribution is standard in the estimation of production and cost frontier functions. Alternative distributions are the exponential, truncated normal or the gamma distribution. See Kumbhakar & Lovell (2000), page 148 for a discussion. In a preliminary analysis we also used the exponential distribution. The results in term of level of efficiency were slightly higher to the one obtained by imposing a half normal distribution but the ranking was similar (correlation of the two inefficiency terms 0.96).

[8] The five utilities in the respective countries are: Stadtwerke Münster (Germany); ENI (Italy); Qurrent (Netherlands); Aziende Industriali di Lugano (Switzerland) and Stadtwerk Winterthur (Switzerland).

proposed econometric methods that allow to take into account the problems related to unobserved heterogeneity and to distinguish transient from persistent efficiency in an effective way.[9]

The variables used in the estimation of residential electricity demand are described below and summary statistics are presented in Table 1. Due to space restrictions we only present means and standard deviations in Table 1. In the Appendix in Table 4 the reader can find also minimum and maximum values for all variables.

Electricity Consumption

Residential electricity consumption in kWh – the dependent variable in our models (see section 3) – can vary substantially across households. Values for the year 2016 in the sample at hand range from 383 kWh to 59991 kWh, with a mean value of around 3751 kWh. As shown in Table 1, electricity consumption differs across countries too. Unfortunately, we did not have information on the electricity consumption of 2027 households (42%), which is why we had to drop those observations. From the remaining sample, we further exclude households that exhibited a negative consumption or other unrealistic values.[10] As residential electricity prices could not be observed in all countries considered, we assumed that they are constant within utilities. Hence, the price effect can be captured with utility-specific dummies in the models.

Dwelling Characteristics

The first dwelling attribute is the number of square meters (*sqm*). Over the entire sample, mean living area amounts to around 125m^2, although Swiss and Dutch dwellings seem to be much larger than Italian ones on average. This may partly be explained by the higher fraction of single family houses (*is_sfh*) in the two first-mentioned states.[11] Three dummy variables indicate the period in which a house or apartment was built. We use four categories: before 1940, between 1940 and 1970, between 1971 and 2000 and after 2000 (reference). It is further known in which of the four utility service areas the dwelling is located.

[9] See Filippini & Greene (2016) for an overview.

[10] We excluded consumption values by introducing household specific minimum consumption values. These minima were calculated by summing up consumption values of the most efficient appliances on the market at the beginning of 2018 in case fridges or freezers exist in a dwelling. The same logic was applied to the number of cycles of dishwashers, washing machines and tumble dryers. Additionally, 40 kWh per 10 square meter of living space was imposed for lighting. A sensitivity analysis using values from 20 to 80 kWh per 10 square meter for lighting, confirm the results. Unrealistic consumption values can arise due to several reasons. For instance, the consumption of people that moved in within 2016 might have not been measured for the entire year or the consumption of prosumers recorded by the utility does not reflect the true electricity used.

[11] Single-family houses are semi-detached, detached as well as terraced houses.

Table 1: Descriptive statistics.

	Overall (N=1620)		Switzerland (N=686)		Italy (N=756)		Netherlands (N=178)	
Variable	**Mean**	**Std. Dev**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev**
kWhtotalEL	3750.93	3972.28	4978.6	5047.27	2513.66	1215.05	4274.44	5175.55
hs1	0.16	0.37	0.16	0.37	0.15	0.36	0.19	0.39
hs2	0.39	0.49	0.43	0.5	0.33	0.47	0.48	0.5
hs3	0.20	0.40	0.15	0.36	0.25	0.43	0.13	0.34
hs4	0.25	0.44	0.26	0.44	0.26	0.44	0.2	0.4
univ	0.51	0.50	0.6	0.49	0.37	0.48	0.77	0.42
inc_1500	0.06	0.24	0.01	0.08	0.12	0.32	0.02	0.15
inc_1to4k	0.34	0.47	0.09	0.28	0.54	0.5	0.48	0.5
inc_4to9k	0.28	0.45	0.4	0.49	0.15	0.36	0.39	0.49
inc_9kpl	0.31	0.46	0.5	0.5	0.19	0.39	0.11	0.31
sqm	124.98	60.47	139.77	64.62	109.58	50.5	133.43	66.89
is_sfh	0.51	0.50	0.54	0.5	0.41	0.49	0.78	0.41
has_fr2	0.23	0.42	0.25	0.43	0.21	0.41	0.28	0.45
has_freezer	0.46	0.50	0.66	0.47	0.29	0.45	0.44	0.5
spheat_el	0.09	0.28	0.16	0.37	0.02	0.13	0.1	0.29
waheat_el	0.13	0.34	0.23	0.42	0.05	0.23	0.11	0.31
ac	0.30	0.46	0.07	0.25	0.56	0.5	0.05	0.22
none_appl	0.19	0.39	0.21	0.41	0.17	0.38	0.18	0.39
bulbtot	24.18	15.47	27.93	18.36	20.76	11.87	24.26	13.36
nmeals_el	3.83	4.75	7.86	3.91	0.5	2.28	2.48	3.58
ndishwcy	3.39	2.54	3.56	2.33	3.15	2.67	3.78	2.68
nwashing	3.73	2.74	3.08	2.59	4.3	2.79	3.78	2.58
ndrying	1.08	1.98	1.26	1.92	0.77	1.92	1.72	2.24
nentt	8.10	6.19	7.07	6.02	8.61	6.02	9.89	6.9
lit_index	4.59	1.69	5.04	1.66	4.01	1.53	5.33	1.65
lit_index_k	2.38	1.31	2.71	1.32	1.97	1.17	2.83	1.32
lit_index_s	2.21	0.74	2.33	0.68	2.04	0.76	2.51	0.64
ail	0.12	0.32	0.28	0.45				
eni	0.47	0.50						
qurrent	0.11	0.31						
sw	0.30	0.46	0.72	0.45				
blt1940	0.17	0.38	0.21	0.41	0.12	0.32	0.25	0.43
blt1970	0.24	0.43	0.22	0.42	0.26	0.44	0.21	0.41
blt2000	0.38	0.49	0.35	0.48	0.43	0.5	0.32	0.47
blt2015	0.21	0.41	0.22	0.41	0.2	0.4	0.22	0.41
wabs5to8	0.07	0.26	0.1	0.3	0.06	0.24	0.04	0.19
wabs8pl	0.04	0.20	0.02	0.16	0.05	0.22	0.06	0.24
dabs1to3	0.15	0.36	0.12	0.32	0.2	0.4	0.06	0.23
dabs4pl	0.03	0.18	0.01	0.09	0.06	0.23	0.03	0.17

Household Composition and Socioeconomic Attributes

Our data set contains information on the number of people living regularly in the residence. We built four categories: single (*hs1*), two-person (*hs2*) and three-person (*hs3*) households, as well as apartments or houses that were occupied by more than three residents (reference category). We excluded participants that stated a household size of zero. In all countries considered, two-person households represent the most frequently observed category.

We further obtained data on the average number of full weeks within a year and the average number of days within a week a residence is completely unoccupied, e.g. due to work-related projects, vacations or stays at a second home. We account for unoccupied residences within the weekly schedule by using two dummies that indicate an average absence of more than three (*dabs4pl*) or between one and three days (*dabs1to3*) a week. Similarly, we controlled for homes that are completely unoccupied for more than eight (*wabs8pl*) or between five and eight (*wabs5to8*) weeks within a year.

Finally, we account for level of education and income. The former is captured by a variable indicating whether a participant had tertiary education (*univ*). The share of respondents holding a university degree is quite high in both the Netherlands and Switzerland compared to Italy. Three dummy variables are used to control for the level of income: Incomes below 1500 Euro per month, incomes between 1500 and 4500 Euros per month and incomes between 4500 and 9000 Euros per month. Incomes higher than 9000 Euros per month are used as reference category.

Energy Services and Appliance Stock

Data on the consumption level of several energy services is available. The average number of light bulbs (*bulbtot*) ranges between 20 and 30 across the countries considered. Number of warm meals cooked on an electric stove (*nmeals_el*) represents the sum of average total number of prepared lunches and dinners per week. This number seems to be particularly low for Italy, which is because most Italian households use gas for cooking. Swiss household primary use electricity for meal preparation and the Dutch ones both energy sources. Number of entertainment services consumed in a typical day (*nentt*) is the sum of total hours of usual daily usage of all TVs and computers within the residence.

Dishwashers, washing machines and tumble dryers are used at a quite similar frequency across the three countries. The number of washing cycles is around 3.5 on average for both washing machine (*nwashing*) and dishwasher (*ndishwcy*). Participants only used dryers (*ndryin*) about once

a week on average. In our estimations, we sum up the number of washing and drying cycles to one variable.

Dichotomous variables capture whether a household owns a second fridge (has_fr2), a separate freezer (*has_freezer*), an air conditioner or a special energy intensive appliance (*none_appl*) like a sauna, swimming pool or home theatre system. Other binary variables control for the presence of an electric space (*spheat_el*) or water (*waheat_el*) heating system, as those systems increase electricity consumption substantially compared to dwellings that use oil or gas-based heating.

Energy- Related Financial Literacy

As mentioned in section 3, the survey included eight questions that account for several dimensions of energy-related financial literacy. Five of these eight questions tried to find out if the households know the electricity price, the electricity consumption of some appliances and the concept of risk diversification, whereas the remaining three questions were structured to collect information on the level of cognitive skills of the households in performing an investment analysis and computing the lifetime cost of an appliance. Two out of these three questions ask respondents to make calculations considering the inflation rate and the concept of compound interest rate and the third question targets computation of the lifetime cost of an appliance. For the estimation of Equation (2) we decided to use a general index of energy-related financial literacy (*lit_index*; values from 0 to 8) in one specification, whereas we use two specific literacy indexes in another specification.[12] One index (*lit_index_k*; values from 0 to 5) should reflect the level of energy related knowledge, whereas the second index (*lit_index_s*; values from 0 to 3) should represent the level of cognitive abilities of the households in doing an investment calculation.

[12] In computing the literacy indexes used in the empirical analysis we made the assumption that each literacy question has the same weight. Therefore, a correct answer receives one point and the indices are computed by adding the number of correct answers.

5. Results

The electricity demand model in Equation (2) has been estimated using the maximum likelihood estimator for cross-section data proposed by Aigner et al. (1977) and implemented in Stata. Table *2* displays the regression results for the four frontier models we estimated. In two of those models, namely the ones presented in column (1) and (2), we use the general index of energy-related financial literacy, while in column (3) and (4) we use the two specific literacy indices. One index reflects the level of energy-related knowledge while the second index represents the level of cognitive abilities in doing an investment calculation. Further, columns (1) and (3) include the three income dummies, whereas columns (3) and (4) do not. We introduce these two models without the income dummies, as in the sample there is a significant portion of households, that did not report an income. Thus, in columns (3) and (4) we gain almost 500 observations.

The majority of the estimated coefficients show the expected signs and are statistically significant. Lambda (λ) is significant in all four specifications.[13] This implies significant inefficiency in the sample households. Finally, the magnitude of the coefficients is remarkably similar across all models.

The coefficients of the income dummies in column (1) and (3) are insignificant, except of one coefficient. This is likely due to the fact that in the model we are controlling for several variables that are correlated with income, such as the size of the home and the presence of specific appliances. All of these coefficients are positive and strongly significant. Furthermore, the models (1) and (3) do not show any major differences compared to the specifications in column (2) and (4) concerning the resulting coefficients.

Moreover, the household size seems to play an important role, as households with one, two or three members use less electricity than households with four or more members. While the university degree of the respondent does not seem to play a significant role, the size of the house and the indicator of whether the dwelling is a single-family house shows a positive and significant impact on the consumption of electricity.

In addition, the coefficients on the presence of electric space heating, water heating, second fridge or a freezer are likewise positive and significant. Moreover, also the attendance of air conditioning,

[13] Lambda (λ) is the ratio of the standard deviation of the inefficiency term and the standard deviation of the stochastic term and gives information on the relative contribution of u_i and v_i on the decomposed error term ε_i.

special appliances (like sauna, solarium etc.) and the total number of light bulbs show positive and significant coefficients.

Further, the number of meals cooked on electric stoves do not have a significant impact, while all other energy services, such as the number of washing and drying cycles, the number of dishwasher cycles as well as the number of TV and computer hours, do have a positive and significant impact on electricity consumption.

In the model specification in column (1) and (2) we use the general index of energy-related financial literacy, that has a significant and negative impact on electricity consumption, meaning that respondents with a higher attainment in the energy-related financial literacy score use less electricity *ceteris paribus*. Further, in the two models in column (3) and (4), where we use the two specific literacy indexes (energy-related knowledge and cognitive abilities), we can see that the energy-related knowledge does not have a significant impact, whereas the level of cognitive abilities of the households in doing an investment calculation, has a negative and significant impact. This provides evidence that respondents attaining a higher score in the cognitive abilities to implement an investment calculation are associated with lower electricity consumption. As discussed in Blasch et al. (2017a), the fact that households with a higher level of literacy consume less electricity, implies that it is possible to identify different demand frontier functions conditional on the level of literacy. This also means that the frontier is shifted, depending on the different values of the index. Furthermore, the fact, that the cognitive abilities in doing an investment calculation play a more effective role than the energy-related knowledge, is indicative of the importance of removing structural problems of investment decisions for improving energy efficiency in the residential sector. This goes in line with the findings in Blasch et al. (2017a).

Finally, the dummies indicating longer absence do not seem to play a significant role, except absences of 8 weeks and more have a significant and negative impact on electricity consumption. Also, the dummies for the building period are insignificant across all four models.

Table 2: Estimated coefficients (p-values in parentheses)

	(1)	(2)	(3)	(4)
inc_1500	-0.0232		-0.0254	
	(0.682)		(0.654)	
inc_1to4k	-0.0473		-0.0480	
	(0.166)		(0.160)	
inc_4to9k	-0.0507*		-0.0499	
	(0.098)		(0.104)	
hs1	-0.256***	-0.276***	-0.255***	-0.275***
	(0.000)	(0.000)	(0.000)	(0.000)
hs2	-0.0990***	-0.112***	-0.0999***	-0.113***
	(0.002)	(0.000)	(0.002)	(0.000)
hs3	-0.0599*	-0.0567*	-0.0605*	-0.0573*
	(0.089)	(0.053)	(0.086)	(0.051)
univ	0.000900	-0.0131	0.00162	-0.0126
	(0.972)	(0.548)	(0.950)	(0.563)
ln_sqm	0.247***	0.268***	0.247***	0.269***
	(0.000)	(0.000)	(0.000)	(0.000)
is_sfh	0.117***	0.119***	0.115***	0.116***
	(0.000)	(0.000)	(0.000)	(0.000)
has_fr2	0.0785***	0.0734***	0.0772***	0.0721***
	(0.007)	(0.003)	(0.008)	(0.004)
has_freezer	0.143***	0.131***	0.142***	0.131***
	(0.000)	(0.000)	(0.000)	(0.000)
spheat_el	0.276***	0.316***	0.275***	0.316***
	(0.000)	(0.000)	(0.000)	(0.000)
waheat_el	0.453***	0.471***	0.453***	0.471***
	(0.000)	(0.000)	(0.000)	(0.000)
ac	0.0896***	0.0959***	0.0915***	0.0967***
	(0.004)	(0.000)	(0.003)	(0.000)
none_appl	0.0596**	0.0539**	0.0586*	0.0531**
	(0.049)	(0.037)	(0.053)	(0.040)
ln_bulbtot	0.0830***	0.0710***	0.0859***	0.0730***
	(0.001)	(0.001)	(0.001)	(0.001)
ln_nmeals_el	0.0215	0.0186	0.0213	0.0184
	(0.240)	(0.263)	(0.246)	(0.269)
ln_dish	0.0997***	0.0853***	0.0990***	0.0851***
	(0.000)	(0.000)	(0.000)	(0.000)
ln_washin	0.139***	0.141***	0.139***	0.141***
	(0.000)	(0.000)	(0.000)	(0.000)
ln_entt	0.0964***	0.0938***	0.0965***	0.0932***
	(0.000)	(0.000)	(0.000)	(0.000)
ln_lit_index	-0.0819**	-0.0532*		
	(0.019)	(0.051)		
ln_lit_index_k			-0.0249	-0.00326
			(0.388)	(0.892)
ln_lit_index_s			-0.103**	-0.0809**
			(0.019)	(0.018)
ail	0.209***	0.194***	0.210***	0.198***
	(0.000)	(0.000)	(0.000)	(0.000)
eni	-0.137***	-0.167***	-0.137***	-0.165***
	(0.008)	(0.000)	(0.008)	(0.000)
qurrent	0.0463	0.0311	0.0486	0.0348
	(0.384)	(0.501)	(0.361)	(0.452)
Building periods	Yes	Yes	Yes	Yes
Absence dummies	Yes	Yes	Yes	Yes
Constant	5.653***	5.590***	5.654***	5.587***
	(0.000)	(0.000)	(0.000)	(0.000)
N	1620	2102	1620	2102
Prob $>\chi^2$	0.0000	0.0000	0.0000	0.0000
λ	1.206	1.092	1.213	1.092
p-Value of λ	0.0000	0.0000	0.0000	0.0000
Log-likelihood	-1038.1	-1296.5	-1037.0	-1295.3

Notes: p-values in parentheses, * p<0.10, ** p<0.05, *** p<0.01

The results of the econometric estimations in Table 2 can be used to estimate the efficiency levels as described in Equation (3). Table 3 provides descriptive statistics for the energy efficiency levels for the households in our sample as well as country-level descriptive statistics for the energy efficiency levels. It shows that with model (1) and (3) the estimated mean efficiency is 70.9% and 70.8%, respectively. In contrast, in model (2) and (4) this value is around 72.8%. This shows, that in the models where we do not use the income dummies (and therefore gain observations) we estimate a slightly lower inefficiency. This result reported in Table 3 indicate that European households could save roughly 27-30% of their energy usage by correcting inefficiencies. We also provide the estimated efficiency levels across countries: while comparing the means of the efficiency levels there are no significant differences, one can find differences across the countries in the standard deviation (around 0.10 for Switzerland, 0.08 for Italy and 0.16 for the Netherlands) and the minimum levels (around 30% for Switzerland, 20% for Italy and 17% for the Netherlands).

Table 3: Estimated efficiency levels

		mean	median	sd	min	max
Overall	(1)	0.709	0.720	0.104	0.176	0.922
	(2)	0.728	0.739	0.095	0.199	0.926
	(3)	0.708	0.720	0.104	0.175	0.922
	(4)	0.728	0.738	0.095	0.199	0.926
CH	(1)	0.709	0.723	0.102	0.278	0.906
	(2)	0.729	0.743	0.092	0.304	0.911
	(3)	0.709	0.722	0.102	0.275	0.906
	(4)	0.729	0.742	0.092	0.304	0.911
IT	(1)	0.715	0.718	0.085	0.204	0.903
	(2)	0.733	0.734	0.077	0.230	0.905
	(3)	0.714	0.717	0.085	0.203	0.902
	(4)	0.733	0.735	0.077	0.231	0.904
NL	(1)	0.683	0.727	0.164	0.176	0.922
	(2)	0.704	0.747	0.153	0.199	0.926
	(3)	0.682	0.725	0.165	0.175	0.922
	(4)	0.704	0.747	0.153	0.199	0.926

6. Conclusions

In this report we present the empirical results on the level of efficiency in the use of electricity for a sample of European households using a stochastic frontier approach. We apply four electricity demand frontier specifications that differ in the explanatory variables. All models control for dwelling characteristics, household composition, the amount of energy services consumed, some special appliances and other socioeconomic variables. The four econometric models yield similar assessments of the current level of efficiency in the use of electricity of the households included in the sample. The mean values of the individual estimates of the energy efficiency are similar and suggest that the efficiency is around 70-72% in our sample. Moreover, the level of energy-related financial literacy seems to play an important role in explaining the level of electricity consumption and the level of the frontier function.

From a policy point of view, the empirical results presented in this report can play an important role. First, the results clearly indicate that there is considerable potential for saving electricity in the residential sector and thus curbing the associated CO_2-emissions. The level of inefficiency is partially due to consumers that do not adopt energy efficient appliances or do not use their appliances in an optimal way. This conclusion is especially relevant, as EU countries agreed on an energy efficiency target for 2030 of 30% within the new Energy Efficiency Directive. Further, improvements in energy efficiency represent a crucial strategy to meet the long-term 2050 greenhouse gas reductions target of the European Union.

Second, the energy saving potential is relatively homogeneous in the residential sector of the European countries considered in this analysis. Third, the European Union might consider promoting the level of energy-related financial literacy through educational programs. Further, another interesting instrument could be the promotion of the diffusion of life-time cost calculators for appliances. The impact of these two instruments is well documented in Blasch et al. (2017c). Of course, bounded rational amongst consumers can also justify the use of energy efficiency regulations and standard on electrical appliances.

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Appendix

Table 4: Complete descriptive statistics.

	Overall (N=1620)				Switzerland (N=686)				Italy (N=756)				Netherlands (N=178)			
Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
kWhtotalEL	3750.93	3972.28	382.9883	59991	4978.6	5047.27	383	36080	2513.66	1215.05	383	10562	4274.44	5175.55	576	59991
hs1	0.16	0.37	0	1	0.16	0.37	0	1	0.15	0.36	0	1	0.19	0.39	0	1
hs2	0.39	0.49	0	1	0.43	0.5	0	1	0.33	0.47	0	1	0.48	0.5	0	1
hs3	0.20	0.40	0	1	0.15	0.36	0	1	0.25	0.43	0	1	0.13	0.34	0	1
hs4	0.25	0.44	0	1	0.26	0.44	0	1	0.26	0.44	0	1	0.2	0.4	0	1
univ	0.51	0.50	0	1	0.6	0.49	0	1	0.37	0.48	0	1	0.77	0.42	0	1
inc_1500	0.06	0.24	0	1	0.01	0.08	0	1	0.12	0.32	0	1	0.02	0.15	0	1
inc_1to4k	0.34	0.47	0	1	0.09	0.28	0	1	0.54	0.5	0	1	0.48	0.5	0	1
inc_4to9k	0.28	0.45	0	1	0.4	0.49	0	1	0.15	0.36	0	1	0.39	0.49	0	1
inc_9kpl	0.31	0.46	0	1	0.5	0.5	0	1	0.19	0.39	0	1	0.11	0.31	0	1
sqm	124.98	60.47	20	400	139.77	64.62	30	400	109.58	50.5	20	400	133.43	66.89	50	400
is_sfh	0.51	0.50	0	1	0.54	0.5	0	1	0.41	0.49	0	1	0.78	0.41	0	1
has_fr2	0.23	0.42	0	1	0.25	0.43	0	1	0.21	0.41	0	1	0.28	0.45	0	1
has_freezer	0.46	0.50	0	1	0.66	0.47	0	1	0.29	0.45	0	1	0.44	0.5	0	1
spheat_el	0.09	0.28	0	1	0.16	0.37	0	1	0.02	0.13	0	1	0.1	0.29	0	1
waheat_el	0.13	0.34	0	1	0.23	0.42	0	1	0.05	0.23	0	1	0.11	0.31	0	1
ac	0.30	0.46	0	1	0.07	0.25	0	1	0.56	0.5	0	1	0.05	0.22	0	1
none_appl	0.19	0.39	0	1	0.21	0.41	0	1	0.17	0.38	0	1	0.18	0.39	0	1
bulbtot	24.18	15.47	1	172	27.93	18.36	1	172	20.76	11.87	4	96	24.26	13.36	4	72
nmeals_el	3.83	4.75	0	14	7.86	3.91	0	14	0.5	2.28	0	14	2.48	3.58	0	12
ndishwcy	3.39	2.54	0	8	3.56	2.33	0	8	3.15	2.67	0	8	3.78	2.68	0	8
nwashing	3.73	2.74	0	15	3.08	2.59	0	15	4.3	2.79	0	15	3.78	2.58	0	12
ndrying	1.08	1.98	0	15	1.26	1.92	0	15	0.77	1.92	0	15	1.72	2.24	0	10
nentt	8.10	6.19	0	48	7.07	6.02	0	48	8.61	6.02	0	46	9.89	6.9	1	35
lit_index	4.59	1.69	0	8	5.04	1.66	0	8	4.01	1.53	0	8	5.33	1.65	1	8
lit_index_k	2.38	1.31	0	5	2.71	1.32	0	5	1.97	1.17	0	5	2.83	1.32	0	5
lit_index_s	2.21	0.74	0	3	2.33	0.68	0	3	2.04	0.76	0	3	2.51	0.64	0	3
ail	0.12	0.32	0	1	0.28	0.45	0	1								
eni	0.47	0.50	0	1												
qurrent	0.11	0.31	0	1												
sw	0.30	0.46	0	1	0.72	0.45	0	1								
blt1940	0.17	0.38	0	1	0.21	0.41	0	1	0.12	0.32	0	1	0.25	0.43	0	1
blt1970	0.24	0.43	0	1	0.22	0.42	0	1	0.26	0.44	0	1	0.21	0.41	0	1
blt2000	0.38	0.49	0	1	0.35	0.48	0	1	0.43	0.5	0	1	0.32	0.47	0	1
blt2015	0.21	0.41	0	1	0.22	0.41	0	1	0.2	0.4	0	1	0.22	0.41	0	1
wabs5to8	0.07	0.26	0	1	0.1	0.3	0	1	0.06	0.24	0	1	0.04	0.19	0	1
wabs8pl	0.04	0.20	0	1	0.02	0.16	0	1	0.05	0.22	0	1	0.06	0.24	0	1
dabs1to3	0.15	0.36	0	1	0.12	0.32	0	1	0.2	0.4	0	1	0.06	0.23	0	1
dabs4pl	0.03	0.18	0	1	0.01	0.09	0	1	0.06	0.23	0	1	0.03	0.17	0	1