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## Behavioral Attitudes towards Energy Saving: Empirical Evidence from France

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## **Abstract**

This paper intends to examine the key drivers of household environmental attitudes and energy-saving behavior using both observed and stated attitudinal factors. Beginning with an assessment of energy-saving behaviors Item Response Theory (IRT), we associate hierarchical multivariate regression with an innovative variable selection approach via Elastic Net Selection (ENS). Our empirical study is based on data from the 2012 ENERGIHAB<sup>1</sup> project survey. Empirical evidence in this article contributes with new insights about the main explanatory factors of household energy-saving behavior. The main results further suggest that energy-saving behavior tends to fluctuate throughout time in households. Our findings and approach generate broader methodological insights into energy efficiency analysis through behavioral aspects.

**Keywords:** Adaptive Elastic Net; Energy efficiency; Energy-saving behavior; Household attitude; Item response theory; Residential energy consumption.

**Jel Codes:** (C21); (C4); (D10); (Q21).

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## 1. Introduction

To mitigate climate change, preserve resources, and improve environmental quality, crucial changes in household, industry and producer behavior will be of great interest (Nauges and Wheeler, 2017). In this article, we contribute to environmental literature on energy demand and energy-saving behavior by investigating the determinants of household observed and stated energy-saving behavior in France.

A substantially growing body of environmental economics literature has emerged investigating the main variables that affect energy demand and household energy-saving behaviors (Wicker and Becken, 2013; Bélaïd and Garcia, 2016; Andor and Fels, 2018; Oberst, et al, 2019). The findings from these recent studies support the argument that behavioral interventions may be a potent energy policy instrument.

The residential sector has been a fundamental target for energy efficiency policy, given its huge potential for energy saving. According to several studies, the residential sector has the largest potential for delivering long-term, significant, and cost-effective energy consumption reduction and related greenhouse gas emissions (Pelletier, 2017; BPIE, 2014).

Direct policy interventions, in recent decades, in the form of mandatory energy labelling, dwelling certification and standards, and investments in energy-efficiency remain insufficient to achieve the energy efficiency targets in most countries. The International Energy Agency (IEA, 2018), claims that about 80% of the economic potential for energy efficiency in buildings remains untapped, largely due to non-technical barriers. Moreover, despite growing emphasis on energy-saving behavior as an energy efficiency instrument, our understanding of its drivers and its effects on household energy demand remains thin. In addition, among these studies, the

findings are quite mixed. Starting from this point, our article contributes new insights about the drivers of household energy-saving behavior. This alludes to the importance of empirically examining the relationship between household socio-economic characteristics and dwelling characteristics in explaining household energy-saving behavior.

The European residential building stock is largely composed of buildings with poor energy performance, accounting for the largest share of total primary energy consumption in the majority of the region's countries. This sector is not only a large consumer of energy, but also a major emitter of greenhouse gas emissions. In France, about 30% of the total energy consumed and 20% of CO<sub>2</sub> emissions are attributed to the residential sector (CGDD, 2015). Consequently, improving energy efficiency in the existing housing stock is one of the most effective ways of enhancing the reduction of greenhouse gas and pollutant emissions. Therefore, a clear understanding of the factors resulting in higher energy efficiency as a result of reducing domestic energy consumption will bring a multitude of benefits to both the economy and to society.

After hosting COP21 in the wake of the global adoption of the Paris Climate Agreement, the French government adopted a new policy called the Energy Transition for Green Growth bill (MEES, 2016), which suggested an ambitious goal for improving energy efficiency in the housing sector and achieving the necessary greenhouse gas emissions reductions. The cornerstone of this policy relies on accelerating a deep renovation of the existing housing stock. In fact, the entire stock should reach the level of low energy buildings i.e. 80 kWh per year and m<sup>2</sup>, by 2050 (Pelletier, 2017). To foster this energy transition and achieve significant energy use reduction in the housing sector, the French Ministry for an Ecological and Solidary Transition has introduced

various financial incentives and regulatory tools intended to fulfill the following goals: (i) simplify zero interest loans (“Eco-PTZ”); (ii) enhance energy efficiency in new dwellings (all dwellings will be built to the low-energy building (LEB) standard by 2050); (iii) and reinforce training in the construction industry to provide a boost to construction skills (MEES, 2016).

Various factors influence the ways in which energy is used in homes, such as energy prices, household and dwelling characteristics, access to delivered energy, climate, home appliance types and efficiencies, energy sources and energy-related policies. As we mentioned above, occupant behavior and attitudes towards domestic energy saving have been studied heavily in a wide range of multidisciplinary studies and have captivated growing attention in various national energy policy measures (Ohler and Sherrilyn, 2014; Quaglione et al., 2017; Belaid et al., 2019; Ziegler, 2019). Currently, energy savings based on behavioral and attitudinal changes have been accepted as important blind spots in our understanding of residential energy demand. They also hold huge potential for reducing domestic energy demand. Accordingly, behaviors and attitudes are considered as critical factors affecting the deployment and expansion of energy efficient technologies and the sustainability of energy systems (OECD, 2016).

This conjecture is the foundation of the present article, aiming to answer calls in recent literature to drive more insights on the explanatory factors of household energy-saving behavior (Bélaïd and Garcia, 2016; Lévy et al., 2014, 2017; Quaglione et al., 2017). While there is an increasing number of studies which focus on the determinants of domestic energy use, there is currently a lack of empirical studies that analyze

occupant energy-saving attitudes and behaviors (Bélaïd, 2016; Lévy and Bélaïd, 2017; Levesque et al., 2019).

This research recognizes that achieving energy efficiency goals requires a holistic approach of integrating the complexities of household behaviors and attitudes in order to capture the underlying drivers of energy-saving behavior. In addition, standard ‘traditional’ studies have commonly employed linear regression methodologies to model household energy-saving behavior using a limited number of factors and, in doing so, have failed to account for its complexities. Therefore, this paper contributes to energy-saving literature by extending the analysis in three important ways. First, we incorporate a wide range of factors controlling for occupant energy-saving behavior attributes in the model. By including the different facets of energy-saving behavior, this study provides a comprehensive delineation of the factors leading to efficient energy-saving behavior. While previous studies have mainly focused on a small number of predictors, we instead suggested a holistic approach assessing simultaneously different key drivers in household energy-saving behavior. A second contribution of this study pertains to the development of an innovative empirical approach designed to untangle the complexity of the energy-saving spectrum. Our empirical approach includes an Item Response Theory (IRT) model associated to hierarchical multivariate regression with an innovative variable selection approach via Adaptive Elastic-Net regularization method. IRT score-based measurement offers significant advantages as it takes into consideration the differences in behavioral difficulty and inconsistency within behavior domains. Finally, this paper intends to enrich the ongoing empirical literature on energy-saving behavior and attitudes. Due

to a lack of information and disaggregated data on household energy usages, empirical literature has been relatively silent regarding the role of energy-saving behavior in shaping residential energy consumption (Bélaïd and Garcia, 2016). Therefore, the research question, methodological framework, and empirical results of this article may pave the path for further research on this topic.

In this context, the purpose of this study is to provide a better understanding of the main drivers of household environmental attitudes and energy-saving behavior to guide energy policymaking to promote more sustainable consumption patterns. From a policy perspective, this study aims to provide further insight into improving the effectiveness and efficiency of environmental policies, which affect households' energy efficiency behavior. Our empirical approach builds on a broad and practical conceptual framework, which embraces a range of energy-saving ecological behaviors and four dimensions of influencing factors: (i) housing attributes; (ii) socio-demographic factors; (iii) ideological and situational factors; and (iv) energy control solutions and obstacles.

The remainder of this paper proceeds as follows: Section 2 provides a brief overview of the theoretical background and presents a literature review. Section 3 describes the data and the econometric methodology. We report our empirical findings in Section 4. Section 5 draws conclusions and offers some policy implications based on the empirical results of the model.

## **2. Theoretical context and research hypothesis**

In recent years, researchers have sought to develop more comprehensive frameworks of residential energy consumption to provide policymakers with useful



insights to promote future energy conservation policies and more energy-responsible lifestyles.

The resulting body of literature has varied in terms of: (i) the research topic, such as energy efficiency, energy demand management and reduction, the rebound effect, and/or energy conservation, fuel poverty, etc. (Belaïd et al., 2018; Belaïd, 2018, 2019); and (ii) the research approach, such as conceptual, methodological, and/or unit of analysis, etc. (Khazzoom, 1980; Turner, 2013; Bélaïd, 2016). Nevertheless, many of these studies have been dominated by a technical approach which neglects the important role of household behavioral and attitudinal factors in shaping residential energy demand (Henly et al., 1988; Brounen et al., 2012; Bélaïd, 2017; Lévy and Bélaïd, 2017).

In this section, we briefly review different strands of the literature by examining household energy-saving drivers and the linkages between energy consumption and behavioral factors. In addition, we explore new perspectives, which highlight additional factors that are more relevant to the relationship between individual preference for energy-saving and energy demand than that which is available in the existing literature.

Many recent studies have argued that residential energy consumption is a complex socio-technical phenomenon shaped by various interrelated factors (Labandeira et al., 2006; Gillingham et al., 2012; Estiri, 2015; Belaïd, 2016). Moreover, complexities of consumer lifestyles and the role of individuals' behavior in the energy demand process have contributed to ambiguities and a partial understanding of residential energy consumption features. Previous research has typically explored the antecedent of household environmental behavior using a different methodological

approach. We distinguish three main theoretical perspectives (Markle, 2013), including: (i) the value-belief norm theory (Stern, 2000); (ii) the theory of planned behavior (Ajzen, 1985); and (iii) the grid-group cultural theory (Mamadouh, 1999). In addition, this stream of research has been dominated by a psychological approach; little theoretical consideration has been paid to the empirical assessment of household pro-environmental behavior and its drivers. Markle (2013) argued that empirical measurements of pro-environmental behavior would allow for comparison between studies and for the assessment of the strengths and weaknesses of different theoretical approaches. Broadly, other studies explore existing research on the influencing factors of energy-saving behavior. Ding et al. (2017) argued that these factors can be divided into three categories: individual, contextual or situational, and socio-demographic factors.

**Individual factors** are related to formed ideas, accumulated experience, and habits developed by households. These individual factors include both objective and subjective characteristics. Studies dealing with these factors mainly use questionnaires and examine the findings using environmental psychology theory (Sun and Jiang, 2013). For example, Darnton et al. (2011) highlighted that household habits play a crucial role in shaping daily energy-saving behavior.

**Contextual factors** refer to the influence of environmental beliefs, social norms, costs, policy regulations and incentives. Some researchers have argued that contextual factors have significant effects on household energy-saving behavior (Ertz et al., 2016; Gadenne et al., 2011). Using a logistic regression model based on a randomly selected sample of 816 residents in Beijing, Wang et al. (2011) highlighted that contextual factors

have a significant effect on electricity-saving behavior through the impact of energy-saving awareness and behavioral ability.

**Socio-demographic factors** are mainly related to household features, including income, household structure, age, and gender, which have been the focus of many previous studies on the determinants of energy-saving behavior (Ding et al., 2017; Sardianou, 2007). Sardianou (2007) demonstrated that socioeconomic variables, such as family size or income level, can explain differences in household energy behavior. Using French data, Belaïd and Garcia (2016) argued that it is possible to expand the household energy consumption life-cycle theory to energy-saving behaviors.

More recently, a flurry of literature has emerged examining the promotion of household pro-environmental or pro-energy-saving behaviors (e.g. Sovacool and Blyth, 2015; Sütterlin et al., 2011).

Drawing on the existing literature reviewed above, we argue that although this literature identifies various dimensions of influencing factors, the relationships between them have received little attention. Furthermore, previous research shows that the relationship between household behavior and domestic energy consumption is very complex, and that current research approaches used in the literature fail to incorporate the entirety of this complexity. Consequently, we know very little about the processes and determinants of residential energy-saving behavior, which has obstructed a clear understanding of what is necessary for effective policies on energy efficiency. This paper is concerned with understanding the role of energy-saving behavior in shaping residential energy consumption patterns. Unlike the proposed research, previous research on the factors influencing energy-saving behavior did not fully consider the effects of the various factors. Based on previous findings from the

literature reviewed above, this study explores four categories of variables that could impact energy-saving behavior: (i) housing attributes; (ii) socio-demographic factors; (iii) ideological and situational factors; and (iv) energy control solutions and obstacles. More specifically, this study investigates five theoretical hypotheses.

**H1:** The relationship between energy-saving behavior intensity and age follows an inverted U-shape curve.

**H2.** Energy-saving behaviors are negatively correlated with household income.

**H3.** Households living in low energy-efficient buildings behave in a more energy-saving manner.

**H4.** Consumers' energy-saving behaviors are positively affected by the availability of home energy control solutions.

**H5.** Ideological and situational factors have a significant effect on household energy-saving behavior.

Fig. 1 displays the hypothesized relationship between the various factors influencing energy-saving behavior considered in this study.

*[Please insert Fig. 1.]*

### **3. Data and modelling approach**

#### **3.1. Data**

We used data from the 2012 "ENERGIHAB - Energy consumption: from the home to the city. Social, technical and economic aspects" project Survey. ENERGIHAB is a multidisciplinary research project focusing on energy consumption and use in the French residential sector. In the framework of this project, we implemented a study on

the main driver of residential energy demand. The survey collected information on broad attitudes concerning energy consumption, environmental preoccupations, refurbishment work, and home comfort, as well as household socioeconomic attributes, housing characteristics, home appliances, energy types, and housing energy consumption.

The ENERGIHAB survey is a detailed, official cross-sectional survey conducted on a region-representative sample of Ile-de-France (Ile de France is the most populated of the thirteen French regions), combining various types of data about housing characteristics, household attributes, and behavioral and attitudinal factors. The basic sample resulted from a quota sampling method, which is a non-probabilistic version of the stratified sampling approach. The sample is representative of the population of the Ile-de-France region in terms of household structure, income, type of housing, occupation status, and urban location.

In total, the survey consists of about 400 questions and requires one hour to complete, on average. Survey participants are interviewed based on an *ad hoc* telephone interview. A total of 1,950 households completed the questionnaire. The respondent for these residential energy questions typically represents the household responsible person (HRP). The main questionnaire was built around seven key parts, including: (1) Housing occupancy status and dwelling characteristics (e.g., housing size, year of built, etc.); (2) Household socioeconomic attributes (e.g., income, age, family size, etc.); (3) Room and space occupancy; (4) Home appliance characteristics and uses; (5) Housing refurbishment and renovation strategies; (6) Energy consumption and costs, including energy consumption structure, prices, and quantity; and (7) Household energy-saving behavior and environmental concerns,

including motivation and enthusiasm for saving energy, clean energy awareness, waste management, as well as environment concerns.

### **3.2. Modeling approach**

Our methodological approach consists of two stages. First, we estimate an Item Response Model, taking into consideration the different level of difficulty associated with different behaviors, allowing the construction of a single measure of general energy-saving behavior. The survey used in this study gives us various information characterizing household energy-saving behaviors and attitudes, such as the management of heating and lighting, the use of electrical appliances, domestic waste sorting practices, etc. Secondly, we use a hierarchical linear regression model to examine the main drivers of the occupant energy-saving behavior. The model incorporates four main groups of variables, including household socio-demographic factors, available energy control systems and obstacles, ideological and situational factors, and housing characteristics. In addition, to enhance the accuracy of our model and escape the high dimensionality curse, we use Adaptive Elastic Net Regularisation method (Zou and Zhang, 2009). The conceptual framework of the different factors which can affect household energy-saving behavior is shown in Fig.1.

#### **3.2.1 Item response theory model**

Impacted by the power of habits as well as by cultural norms and social conditions, households may display a wide variety of responses to ecological or environmental concerns (Pickett et al., 1993). Based on Kaiser's general framework to measure ecological behavior (Kaiser, 1998), we argue that an accurate assessment of energy-saving behaviors must overcome two characteristics of ecological behaviors.

The first one consists of the unequal level of effort of different attitudes and behaviors, i.e. that some energy-saving behaviors and attitudes are more arduous to carry out than others. The second characteristic is the existent inconsistency from one behavior to another, owing to the fact that ecological behavior is responsive to a myriad of influences. Therefore, households would seem to be inconsistent in their energy-saving attitude and behavior – that is, what they do one day, they may not do on another. In addition, cultural and social conditions could support one behavior but not another.

To consider the important features and to develop a valid conclusion of the energy-saving behavior scale, it is crucial to smooth these inconsistencies by using a synthetic indicator, grounded on a stochastic measurement approach. The IRT offers a suitable solution to avoiding methodological flaws, which accurately reflects the main features of energy-saving behavior discussed above. The IRT allow us to compare each respondent (household) according to a unique energy-saving behavior scale which takes into consideration the respective obstacle and difficulties related to each attitude and behavior.

The basic notions of IRT rely on the individual items of a test rather than upon an aggregate of the item responses, which more closely resemble a score indicator (Baker and Kim, 2004). Therefore, in this study, we employ an IRT model to estimate the score of the occupant energy-saving behavior, which considers both the difficulty of given ecological behaviors and a household's ability to achieve a certain energy-saving score. IRT considers a class of latent variable models which link mainly dichotomous and polytomous response variables (i.e., manifest factors) to a single latent factor (Baker and Kim, 2004). This method consists in modeling the fundamental

relationship between the IRT-measured construct of the respondent, often denoted as  $\theta$  (in our case,  $\theta$  is the energy-saving behavior), and his or her probability of managing an item (here to adopt such energy-saving attitude).

The energy-saving behavior score items were examined and selected using the Graded Response Model (GRM) proposed by Samejima (Samejima, 1970, 1997). Samejima's approach is based on the assessment of two parameters related to the item. The first parameter  $\beta_{i,k}$ , is known as the 'threshold' parameter. It represents the difficulty parameter of the  $k^{\text{th}}$  category of item  $i$ . The second parameter  $\alpha_i$ , represents the discrimination parameter of item  $i$  and depicts the extent to which an item discriminates between households at different levels of the latent trait.

The parameters are estimated using the Marginal Maximum Likelihood Estimation maximization method, assuming that the respondents represent a random sample. The trace line, or the ICC (Item Characteristic Curve), is the foundation of IRT, which is most commonly described as a logistic function that assesses the relationship between two variables: (i) a household attitude to given energy behaviors (item); and (ii) a personal attitude on the construct computed by the scale. Considering  $\theta_j$ , the energy-saving behavior level of household  $J$ , and  $x_i$ , the ordinal manifest variable, the GRM equation below uses a logistic function and provides the probability of household  $j$  receiving score  $k$  for item  $i$ :

$$P(x_i = k | \theta_j) = P_{x_i,k}(\theta_j) - P_{x_i,k+1}(\theta_j) = \frac{1}{1 + \exp - [D\alpha_i(\theta_j - \beta_{i,k})]} - \frac{1}{1 + \exp - [D\alpha_i(\theta_j - \beta_{i,k+1})]} \quad (1)$$

Where  $\alpha_i$  and  $\beta_{i,k}$  are defined above, and  $f(\theta) = \frac{\exp(\theta)}{1 + \exp(\theta)}$   $\beta_1 \leq \beta_2 \leq \dots \leq \beta_k$  (2)

Table 1 provides an overview of all the variables used to construct the energy-saving behavior score and the related descriptive statistics.



*[Please insert Table 1]*

### **3.2.2 Hierarchical linear regression model specification**

After constructing a score of energy-saving behavior, the second stage of our study examines the salient driver of this score using some explanatory factors. Since our explanatory variables are divided into subgroups, the hierarchical linear regression offers the possibility to test the additional amount of variance added by each block of explanatory variables, i.e., to assess the predictors' contribution to the model, above and beyond previously introduced factors (Pedhazur, 1997). Furthermore, hierarchical regression models are suitable for examining the moderating effects of factors (Hox, 1994). The hierarchical regression, by developing a sequence of linear regression models, is based on a sequential process involving the gradual inclusion of explanatory variables into the model. The effect of a predictor variable, after controlling for other factors, is achieved by computing the variation in the adjusted R<sup>2</sup> at each stage of the model, thereby considering for the increase in variance after each group of factors is integrated into the model (Pedhazur, 1997).

The hierarchical regression model requires choosing a best predictor group interactively between the theoretical assumption and technical consideration. Therefore, in the first stage, we introduce the household's socio-demographic attributes, then those on the available energy control solutions and obstacles, followed by the socio-psychological variables, and, finally, the housing characteristics. The energy-saving behavior score is modelled using the following specification:

$$Y_i = \alpha + \sum_i \beta_i X_i + \sum_i \delta_i Z_i + \sum_i \lambda_i V_i + \sum_i \varphi_i W_i + \mu_i \quad (3)$$

Where  $Y_i$  indicates the energy-saving behavior score;  $X_i, Z_i, V_i,$  and  $W_i$  are the model predictors;  $\alpha, \beta_i, \delta_i, \lambda_i,$  and  $\varphi_i$  are the model coefficients; and  $\mu_i$  is the unobserved error term.

To improve the performance of the regression model and handle the curse of high dimensionality we associate the Adaptive Elastic-Net regularization method (Ad-Enet), which amalgamates some of the ridge regularization and adaptive weighted Lasso shrinkage (Zou and Zhang, 2009). To obtain the Ad-Enet estimates, we solve the following optimization problem:

$$\hat{\beta}_{Ad-Enet} = \left(1 + \frac{\lambda_2}{n}\right) \left\{ \arg \min_{\beta} \|y - X\beta\|_2^2 + \lambda_2 \|\beta\|_2^2 + \lambda_1^* \sum_{j=1}^P \hat{\omega}_j |\beta_j| \right\} \quad (4)$$

Where  $\{\hat{\omega}_j\}_{j=1}^P$  are the adaptive data-driven weights;  $\lambda_1$  and  $\lambda_2$  denote the regularization parameters, in which if we impose  $\lambda_2$  to be zero in Eq. 4, the Ad-Enet provides the adaptive lasso estimates. According to Zou and Zhang (2009), in the presence of large number of predictors, the Ad-Enet enjoys the oracle property, improve the prediction accuracy, and deals with collinearity issue better than the other oracle-like method, including lasso (Tibshirani, 1996) and Smoothly Clipped Absolute Deviation approach (Fan and Li, 2001).

The socio-demographic factors allow for an understanding of the profile of people who adopt the best energy-saving behavior, as well as those, who on the contrary, have a lower score. The main hypothesis is intended to answer the following question: do the income, age, gender, and educational status of an individual have an impact on their adoption of ecological practices? Table 2 shows the socio-demographic variables used in the model.

*[Please insert Table 2]*

The introduction of variables on the household's available energy control solutions and the obstacles (Table 3) leads to a deeper analysis of the factors driving energy-saving behavior. It is indeed a question of studying to what extent the technical factors do or do not have an effect on the adoption of energy-saving behavior. For example, a central heating control system presents a favorable condition for people to adopt energy-saving behavior. Additionally, does this condition systematically contribute to other pro-energy conservation behavior? Furthermore, we examine the moderating effect that these new variables can have on the selected socio-demographic variables. For example, is the measured moderate effect of the socio-demographic factors on energy-saving behavior partially explained by contextual technical factors which foster the adoption of energy-saving behavior?

*[Please insert Table 3]*

We incorporate socio-psychological and ideological variables (Table 4) to add a cognitive dimension to our model. The main objective is to identify household values and opinions regarding their relation to the environment and energy issues, and to test the impact of these variables on energy-saving behavior. This category of factors intends to ascertain whether inhabitants' perception and attitude towards energy-saving contributed significantly to energy-saving behavior. Past research has noted

that beliefs and socio-psychological factors help to fill in technical gaps in the theory of energy-saving behavior (Seligman et al., 1979; Sardianou, 2007).

*[Please insert Table 4]*

Finally, by including the environment within which households' energy-saving attitudes and behaviors are formed, the analytic approach aims to provide a comprehensive delineation of the process that leads from housing characteristics to behavior. In fact, dwelling attributes (Table 5) depict consumer's practices. For example, people may give more importance to heating when they live in large housing unit.

*[Please insert Table 5]*

#### **4. Empirical results and discussion**

##### **4.1. Energy-saving behavior score**

The purpose of the energy-saving score measurement is to define a household's position on the latent trait from a set of observed item responses. First, the IRT model provides initial and an appropriate item's factor loadings considering the item difficulties and ability levels. The estimated parameters of the variables retained in this model are displayed in Table 6. The factors allow us to build a ranking of the energy-saving behavior practice by order of difficulty. The factors range from -2.32 to 5.02 (all statistically significant at the 1% level). Therefore, the three items with the highest degree of discrimination (easiest measures to adopt), in ascending order, are: (i) switching off the light when going out of the house; (ii) switching off the light when going out of the room; and (iii) sorting domestic waste. Otherwise, the three items with

the lowest discrimination degree, in ascending order, are: (i) implementing energy efficient housing refurbishment; (ii) using renewable energy; (iii) and purchasing household appliances according to their energy label.

Secondly, IRT analysis allowed us to build an energy-saving behavior score based the item difficulties and ability levels. This score shows the distribution of the energy-saving levels of the items, with their respective aspects and indicators. We see from Fig. 2 that the standardized score ranges from -4.8 to 2.

*[Please insert Table 6]*

*[Please insert Fig.2]*

#### **4.2. Regression results and hypothesis discussion**

After having built a score of energy-saving behavior for every household, we intend to explain it by using a set of factors in a hierarchical linear regression. Estimated effects from the hierarchical linear regression are displayed in Table 7. In the first model (M1), we examined the effects of the socio-demographic characteristics on household energy-saving behavior. Most of the factors were found to be significant at the 5% level, including the gender, age, ethnicity, and marital status of the HRP. Household size and income are not statistically significant in this model. The regression results suggest, among socio-demographic attributes, that family status was one of the most influential factors in household energy-saving behavior. The results show that a family with children has a positive impact on energy-saving behavior. Concerning the HRP ethnicity, in general, the model shows that a French citizen born in France is more likely to adopt energy-saving attitudes. Belaïd (2016) has shown that

the HRP ethnicity has a significant impact on domestic energy use and that foreign households consume more than French households.

Otherwise, our findings fail to confirm a linear trend between the HRP's age and energy-saving attitudes. We find that households with HRPs between 37 and 50 years old are more likely to adopt energy-saving behavior than persons between 51 and 68 years old, who themselves adopt more energy-saving behaviors than the youngest and the oldest age cohorts (below 36 years old and above 69 years old). This supports the inverted U-shape distribution of the latent ability as a function of the HRP's age. The inverted U-shape pattern of domestic energy consumption first claimed by Fritzsche (1981). Using 1972-73 US data, Firtzsche substantiated the above hypothesis by a significant difference in home energy use with respect to succeeding stages of the family life cycle. Energy consumption tends to fluctuate during the life cycle of the family. Single people tends to consume less energy than a family with children. Energy use decreases after children leave home, but it increases gradually with age, because older people need more comfort and higher temperatures.

Belaïd and Garcia (2016) suggest that individual aspirations are a key feature in explaining the inverted right-hand side of the inverted U-shape, while family size explains the left-hand side (birth of children). Domestic energy demand increases with the succeeding stages of the life cycle (until child-rearing years) up to the point when the children leave the family. After that, energy demand decreases throughout the remaining stages of the household life cycle. However, usage intensity will remain above the levels of the first stage, pre-child stage. Quaglione et al. (2017) have shown that concern about energy-saving issues among HRPs aged 45-54 is higher than among HRPs aged 18-34, but that the concern decreases with age. Nevertheless, the results

support the hypothesis of expanding energy consumption life cycle theory to residential energy-saving behaviors and attitudes (Fritzsche, 1981; Lévy and Bélaïd, 2017). Additionally, our findings suggest that respondents identifying as female display more energy-saving behaviors and attitudes. This result corresponds with the conclusions of previous studies. For example, using 2016 microdata survey of the Italian National Institute of Statistics, Quaglione et al. (2017) conclude that the probability of energy savings decreases among male HRPs.

*[Please insert Table 7]*

The second model (M2), shows that all the variables introduced about the behavioral ability and knowledge have a significant effect on household energy-saving behavior. The introduction of these factors greatly increased the adjusted R<sup>2</sup> of the model from 0.07 to 0.15. The results highlight a positive relationship between the presence of home energy control solutions and energy-saving attitudes. Among the behavioral ability factors, the presence of a temperature monitor is the most influential factor, followed by the presence of a home energy management system. Yue et al. (2013), based on a sample of 638 households in Jiangsu Province (internet survey), argued that behavioral ability factors have a positive moderating effect on household energy-saving behavior.

In addition, the second model reveals a positive and significant effect of household ownership factor. This empirical result supports the theoretical background that home ownership is an explanatory factor for different types of energy-saving behavior. This result is consistent with Walsh's (1989), Barr's et al. (2005) and Sardanou's (2007) findings.

Turning to the third model, the hierarchical regression model confirms that for energy-saving behavior, the adjusted determination coefficients of this model is significantly greater than those of M1 and M2. This result suggests that the ideological and situational factors' have a significant effect on household energy-saving behavior. First, we notice that household ecological and political ideology is not associated with household energy-saving behavior. However, our results suggest that being integrated in a civil society organization, a union, or a political party has a positive and moderate effect on energy-saving attitudes. Therefore, active implication in citizen life makes households more sensitive to ecological and energy issues than ecological and political ideology. Households who consider that their energy bill influences their attitudes have a stronger tendency to adopt energy-reduction behaviors. This depicts a household concern about the amount of energy used, whether for economic or ecological motivations. Additionally, respondents who lived previously in a rural area are less averse to adopting energy-saving attitudes.

Finally, turning to the fourth model, the hierarchical regression results demonstrate that for the housing characteristics considered, the adjusted  $R^2$  of model 4 is moderately greater than those of the previous models (1-3). Most of the control variables do not show significance in explaining household energy-saving behavior. This supports the hypothesis that housing attributes have a weak effect on household energy-saving attitude. Results shows that living in the center of Paris has a significant and negative effect on household energy-saving behavior, all being equal, as far as the Parisians are less likely to adopt an ecological behavior compared to other inhabitants of the Ile-de-France region. This result is not in line with the conclusions of previous research. Druckman and Jackson (2008) and Belaid and Garcia (2016) show that urban



areas could be a significant driver of energy-saving behavior and indicated that living in rural areas is usually associated with high energy use.

## **5. Conclusions and policy implications**

Preoccupations regarding the reduction of residential energy use and its associated carbon emissions have grown significantly in the last decade. In addition, researchers and energy policymakers have begun to perceive the important role that household attitudinal and behavioral factors have on the domestic energy demand. Nevertheless, energy-saving attitudes and behaviors are shaped by a wide range of complex factors and are difficult to understand. However, promoting energy-saving behavior changes and sustainable energy consumption, needs more information and knowledge about what drives consumption and household lifestyle. This article contributes to this knowledge by providing new evidence based on an important empirical case and innovative empirical approach. It reports valuable information on the factors that can be useful in an energy conservation campaign. In addition, this research brings to light the importance of incorporating household energy-saving attitudinal and behavioral attributes into models seeking to untangle the factors that explain residential energy demand.

This research builds on a broad and practical conceptual framework that embraces a score of energy-saving behavior and four dimensions of influencing factors. These factors include socio-demographic attributes, ideological and situational factors, dwelling characteristics, and available energy control solutions and obstacles. We use recent individual data from ENERGIHAB project survey to contribute to this field of nascent research in two ways. First, we construct a single energy-saving behavior score based on an IRT model. Then, we use a hierarchical multivariate

regression model to examine the effects of a wide range of factors, including subjective household perceptions on occupant energy-saving behavior. This study corroborates previous research findings suggesting that household energy-saving is driven by various factors, including socio-economic characteristics, housing attributes, ideological and situational factors, and energy control available solutions and obstacles.

The IRT model suggests initial and an appropriate item's factor loadings considering the household difficulties and ability levels ranged from -2.32 to 5.02 and all statistically significant at 1% level. The factors allow us to build a ranking of energy-saving behavior practices by order of difficulty. In addition, the IRT analysis allows us to build an energy-saving behavior score based on the item difficulties and ability levels. Most of the socio-demographic factors were found to be significant at the 5% level, including the gender, age, ethnicity and marital status of the HRP. In general, being in a family with or without children (as opposed to being single), being a French citizen, and being female, all have a positive impact on energy-saving behavior. Our findings support the inverted U-shape distribution of latent ability as a function of the HRP's age. The hierarchical regression model shows that all of the variables introduced about behavioral ability and knowledge have a significant effect on household energy-saving behavior. In addition, the results confirm that ideological and situational factors have a significant effect on household energy-saving behavior. This study does not aim to be exhaustive in policy implications terms, but rather to specifically identify some factors which may be important to target through policy measures in order to improve occupant pro-energy saving behavior. This provides valuable information on different ways of reducing domestic energy use. From a

policy perspective, this evidence suggests that targeting incentives to decrease energy use are vital to achieving the central policy goals of reducing domestic energy demand. Our results highlight the importance of policies in increasing attention towards changing household habits and finding ways to foster household awareness and responsibility for energy saving.

Energy policymakers may not be able to influence objective contextual factors that consumers face; nevertheless, they can design policies to impact occupant attitudes and perceptions. Fully understanding of the factors influencing energy-saving behaviors is a prerequisite to achieve a significant reduction in residential energy consumption. This would be helpful in designing and implementing the most effective intervention strategies aiming to promote occupant energy-saving behaviors. To induce behavioral changes, occupants need the capability, the opportunity and the motivation to do so. Accordingly, various intervention strategies should be explored to encourage energy-saving behaviors among occupants, including: (i) information and education (e.g., workshops to increase knowledge or understanding); (ii) goal setting and feedback (e.g., assigning an energy reduction target, and giving feedback for households to measure the progress); (iii) persuasion (e.g., using communication to induce positive or negative feelings or stimulate action); (iv) incentives (e.g., creating expectation of reward such as monetary rewards); (v) modeling (e.g., providing example for occupants to aspire or to imitate); (vi) coercion (e.g., creating expectation of punishment or cost); (vii) restriction (e.g., using rules to reduce the opportunity to engage in the target behavior or to reduce the opportunity to engage in competing behaviors) (viii) and enablement (e.g., increasing means and reducing barriers to increase capability or opportunity).

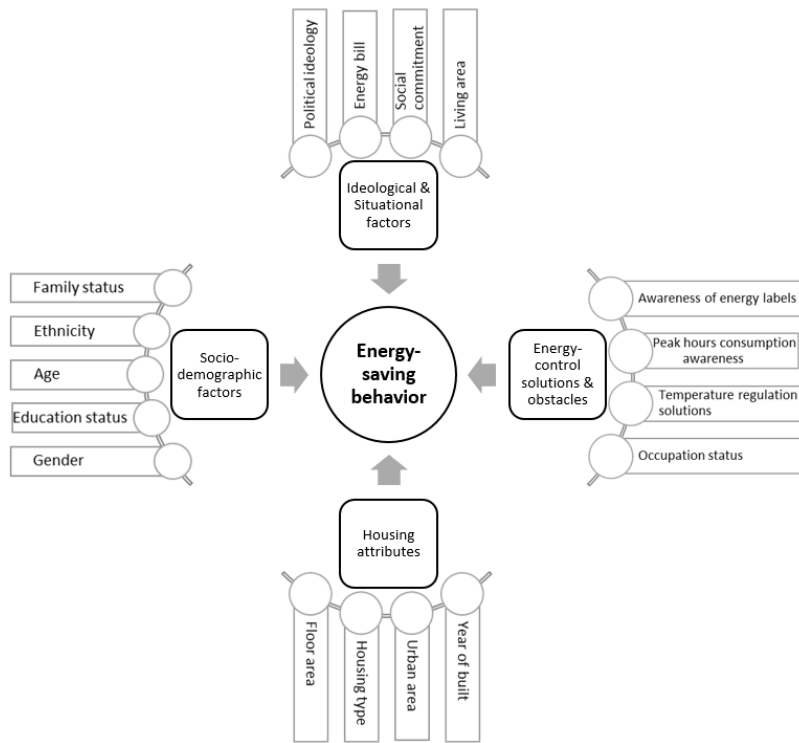
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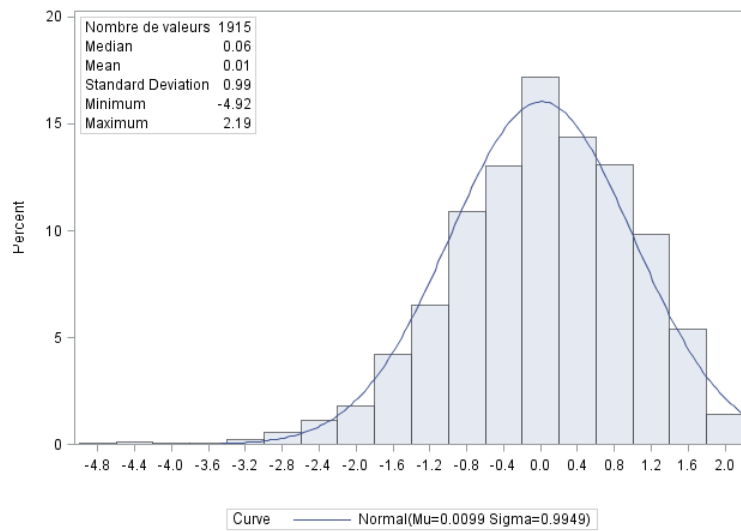
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**Fig. 1.** Conceptual framework for energy-saving behavior of urban households in Ile-de-France



**Fig. 2.** Distribution of the energy-saving behavior score



**Table 1**

Definitions of the variables used to compute the energy-saving behavior score

Variables	Yes	No	NR	Definition
<b>Behavior of energetic regulation</b>				
Temp20_2	57%	31%	21%	Heating temperature in home inferior or equal to 20°C
Room temp19_2	48%	52%		Heating temperature in home equal to 19°C
Heat_bathroom3	51%	49%	0,3%	Bathroom never warmed or warmed by irregularities
Heat_absence 3	58%	42%		Cut or reduce heating when housing is empty during several days
heat_day3	37%	63%		Cut or reduce heating when housing is empty during the day
Heat_aeration3	39%	60%	1%	Cut heating during the aeration of rooms
Regulation_LA	28%	72%		Large appliance regulation
Regulation_PC	48%	18%	34%	Turned off the computer after use
Regulation_TV	57%	28%	15%	Turned off TV after use
Bath_shower	82%	18%		At most one shower or a bath per person and per day
Lights_adapt	87%	13%		Adapt the lights according to time of day
Light_housing 2	98%	2%		Switch off the light when going out of the house
Light_room2	91%	9%		Switch off the light when going out of the room
<b>Control of the air and the heat</b>				
Windows_hot 2	65%	35%		Closure of windows during very hot weather periods
Shutters_hot 3	66%	19%	15%	Closure of shutters during very hot weather periods
<b>Measures favorable to environmental protection (via energy savings or other)</b>				
Energy-saving bulbs 3	68%	32%		Systematic use of the energy-saving bulbs
Waste sorting	88%	12%		Domestic waste sorting practice
Green attitude	60%	40%		Systematic or occasional use of ecological products
Factor_eqpt3	79%	17%	4%	The main decisional factor of choosing large home appliances is the energy label
Ecological_works	4%	96%		Implementation of housing energy efficiency refurbishment
Enrgy2	4%	96%		Renewable energy use

**Table 2**

Socio-demographic factors

Variables	Frequency
<b>Gender</b>	
Men	39%
Women*	61%
<b>Educational status</b>	
No diploma or other*	11%
Diploma	89%
<b>Age</b>	
Less than 36 years old*	10%
37-50 years old	28%
51-68 years old	38%
69 years old and above	24%
<b>Nationality and origin</b>	
French people born in France*	83%
Foreign-born French citizens	6%
Foreigners	11%
<b>Family status</b>	
Couple with or without kids*	55%
Single with or without kids	45%

Note: \*Reference group

**Table 3**

Household's available energy control solutions and obstacle factors

	<b>Yes</b>	<b>No</b>
Knowledge of energy labels on electrical appliances	55%	45%
Knowledge of peak-low consumption hours	93%	7%
Solutions to know the temperature in home	76%	24%
Solutions to control home temperatures	82%	18%
Home owner	55%	45%

**Table 4**

Ideological and situational factors

	<b>Yes</b>	<b>No</b>
Individual has displayed an ecological and political ideology	3%	97%
Individual's behavior is influenced by his/her energy bill	53%	47%
Individual is involved in a civil society organization, a union, or a political party	25%	75%
Individual has lived in a rural area previously	30%	70%

**Table 5**

Housing characteristics

	<b>Frequency</b>
<b>Year of construction</b>	
Before 1948*	24%
1949-1974	21%
1975-1998	19%
After 1999	8%
<b>Urban area</b>	
Paris center	53%
Large city (from 10,000 to 99,999 inhabitants)	10%
Small city (fewer than 9,999)	27%
Rural Area*	10%
<b>Housing type</b>	
Collective housing	59%
Individual housing*	41%
<b>Floor area</b>	
<70 m <sup>2</sup> *	36%
70-150 m <sup>2</sup>	33%
More than 150 m <sup>2</sup>	31%

Note: \*Reference group

**Table 6**

IRT model results

Variable	Estimator
Ecological_works	-2.329***
enrgy2	-2.246***
Factor_eqpt3	-0.610***
Heat_absence 3	0.447***
heat_aeration3	0.523***
Bulbs 3	0.755***
Regulation_LA (RF)	1
heat_bathroom3	1.036***
Heat_absence 3	1.334***
Green attitude	1.394***
Room temp19_2	1.408***
Windows_hot 2	1.601***
Temp20_2	1.603***
Regulation_TV	1.708***
Regulation_PC	1.896***
Shutters_hot 3	2.281***
Heat_bathroom3	2.537***
Lights_adapt	2.894***
Waste sorting	3.065***
Light_room2	3.310***
Light_housing 2	5.022***

Note: \*\*\*, \*\*, and \*, represent level of significance at 1%, 5%, and 10%, respectively.

**Table 7**

Results from the hierarchical linear regression model

Variables	M1	M2	M3	M4	FINAL
Intercept	0.166**	-0.611***	-0.726***	-0.674***	-0.668***
<b>Socio-demographic factors</b>					
Men (vs. women)	-0.146***	-0.145***	-0.139***	-0.142***	-0.140***
Without a diploma (vs. with a diploma)	-0.267***	-0.165**	-0.147**	-0.158**	-0.148**
37-50 years old (vs. 36 years old)	0.242***	0.150**	0.143*	0.154**	0.142*
51-68 years old (vs. 36 years old)	0.165**	0.077**	0.081**	0.108**	0.086**
69 years old and above (vs. 36 years old)	0.041*	-0.063*	-0.038*	0.011*	-0.026*
French citizens born abroad (vs. French citizens born in France)	-0.263***	-0.205**	-0.178**	-0.164*	-0.155**
Foreigners (vs. French citizens born in France)	-0.317***	-0.178**	-0.137*	-0.123	
Single person (vs. in a relationship)	-0.383***	-0.246***	-0.244***	-0.238***	-0.243***
<b>Available solutions and obstacles</b>					
Knowledge of energy labels of the electrical appliances		0.228***	0.205***	0.205***	0.203***
Knowledge of peak hour-low consumption hours		0.116			
Solutions to know the temperature in home		0.408***	0.396***	0.383***	0.386***
Solutions to control the temperature in home		0.297***	0.281***	0.275***	0.282***
Home owner		0.171***	0.171***	0.161***	0.173***
<b>Ideological and situational factors</b>					
Ecological political ideology			0.041		
The energy bill influences my behavior			0.130***	0.127***	0.129***
Commitment in a civil society organization, a union, or a political party			0.095**	0.109**	0.101***
Has already lived in a rural area			0.149***	0.123***	0.123***
<b>Housing characteristics</b>					

Constructed in 1949-1974 (vs. before 1948)				-0.065	
Constructed in 1975-1998 (vs. before 1948)				-0.031	
Constructed after 1999 (vs. before 1948)				0.012	
Located in Paris city center (vs. rural area)				-0.130*	-0.093**
Large city (vs. rural area)				-0.074	
Small city (vs. rural area)				-0.043	
Collective housing (vs. individual housing)				0.072	
70-150 m <sup>2</sup> (vs. <70 m <sup>2</sup> )				-0.075	
More than 150 m <sup>2</sup> (vs <70m <sup>2</sup> )				0.099	
<b>R<sup>2</sup></b>	0.0682	0.1492	0.1587	0.1901	0.2061

Note: \*\*\*, \*\*, and \*, represent level of significance at 1%, 5%, and 10%, respectively.