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Original research article

Demand-side solutions for climate mitigation: Bottom-up drivers of household energy behavior change in the Netherlands and Spain

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ABSTRACT

Households are responsible for 70% of CO_2 emissions (directly and indirectly). While households as agents of change increasingly become a crucial element in energy transitions, bottom-up mechanisms facilitating behavioral change are not fully understood. A scientific understanding of individual energy use, requires eliciting factors that trigger or inhibit changes in energy behavior. This paper explores individual energy consumption practices and behavioral aspects that affect them. We quantitatively study the determinants of three energy actions: (1) *investments* in house insulation, solar panels and/or energy-efficient appliances, (2) *conservation* of energy by changing energy-use habits like switching off unused devices or adjusting house temperature, and (3) *switching* to green(er) electricity sources. To address this goal, we conduct a comprehensive survey among households (N = 1790) in two EU regions: Overijssel, the Netherlands and Navarre, Spain. We use probit regression to estimate how behavioral factors, households' socioeconomic characteristics and structural attributes of dwellings influence energy related actions. Our analysis demonstrates that awareness and personal and social norms are as important as monetary factors. Moreover, education and structural dwelling factors significantly affect households' actions. These results have implications for governmental policies aimed at reducing residential CO_2 footprints and facilitating demand-side solutions in a transition to low-carbon economy.

1. Introduction

Keeping greenhouse gas emissions below critical levels defined by the Paris Agreement is essential for effective climate change mitigation. Mitigation efforts vary from using renewable energy sources, and new energy-efficient technologies, to changing management practices and consumer behavior by introducing policy measures and regulations on both production and consumption sides. However, changes in individual behavior and management practices as part of the mitigation strategy are often understudied [1,2]. It has been proven that human activities and the associated increasing emissions of greenhouse gases (GHGs) are the main causes of global warming [3–6]. On the global scale, households are responsible for 72% of GHG emissions [3,7]. For example, in the UK 74% of total consumer emissions of CO_2 are influenced by households (directly and indirectly) [7]. Households' CO_2 footprint is shaped by different activities: energy use at home, transportation options and diets, each shaped by different factors and decided upon at different time scales. Behavioral change regarding transportation options depends on the availability of public infrastructure and job opportunities close to home, while shifts in diets is a process highly interwind with culture and social norms. Changes in these two CO_2-generating activities are long-term processes, limiting the role an individual household may have in the short-run. At the same time, decisions regarding households' energy use in Europe are decentralized, with an intensive diffusion of alterations in individual energy use observed empirically in the past years [8-14]. Hence, this paper focuses on the residential energy use when studying the role of individual behavioral changes in reducing CO_2 footprint and contributing to climate-change mitigation.

According to Eurostat, European households are responsible for almost one-quarter of total energy consumption in Europe.[1] Yet, despite behavioral change being emphasized as a crucial component of

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[1] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_co3_p3&lang=en

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mitigation strategies worldwide [1,15,16], empirical studies on individual energy-related choices and behavioral factors impacting them are scarce. In particular, while there are surveys exploring the adoption of energy technologies [8,17–23] and examining pro-environmental personal and social norms [24–26], they are rarely considered in combination. Moreover, behavioral factors and energy-technology choices are usually reported in an aggregated format, ignoring the fact that various socioeconomic groups may exhibit different behavioral traits. The increasing scholarly understanding of the bottom-up factors such as households socioeconomic and dwelling characteristics, and behavioral factors behind the demand-side potential for climate mitigation, could guide effective policy development and implementation that differentiates between various household groups and actions.

Why this heterogeneity is important? The essential role of household socioeconomic characteristics on energy-efficient investments (e.g., technology adoption) is acknowledged in several studies. For example, a positive correlation has been shown between income and the probability of investing in energy-efficient technologies [8,19,20,22,26–29]. Some studies report that individuals with a higher level of education are more likely to adopt energy-efficient technologies [21,28–31]. The evidence regarding the impact of age is mixed: some studies suggest that there is a negative correlation [20–22,30-32], other studies report that middle-aged people are more active in this regard compared to youngsters [28]. Notably, these behavioral patterns may differ per type of investment [19]. Other studies highlight the importance of dwelling characteristics for individual choices. The tenure status of the residence (owned or rented) affect a likelihood of investments in energy-efficiency in buildings. In particular, owners are more likely to invest in insulation and energy-efficient appliances than renters [19,33,34]. Other dwelling characteristics – such as type (e.g. detached-house, apartment), size, location (e.g. rural, urban), and age of dwellings – appear to be important drivers of households energy-efficient investments 13,19,20,29,31,35–37]. Among behavioral factors, the literature brings attention to the importance of households' awareness and personal interest for energy decisions [10,23,26,35,38–40].

The current article contributes to this discourse by reporting the results of an original large-scale survey ($N = 1790$) in two the European Union (EU) countries. We present unique data on behavioral and sociodemographic factors of households and their dwelling characteristics, and offer a quantitative analysis of the main drivers and barriers related to household changes in energy-use behavior. The key theories in psychology provide a solid ground for identifying potential behavioral factors that are relevant for behavior changes in energy use. The goal is to quantify which factors – socioeconomic (e.g., income, age), behavioral (e.g., personal and social norms, knowledge and awareness about the environment, social influence) and structural (e.g., size and type of house) – trigger or attenuate a transition to a lower and greener energy footprint at the household level. The innovative contribution of this paper is threefold:

(i) ***Empirical testing of theoretical concepts:*** relying on theories of individual decision making from psychology, it develops a conceptual framework that integrates a variety of behavioral factors potentially relevant for studying energy behavior changes. The role of various behavioral factors is quantitatively studied using survey data;

(ii) ***Heterogeneity:*** our analysis goes beyond the current empirical literature on individual energy behavior by focusing on detailed actions within the three main types of households' choices: investment, conservation, and switching among providers. Within these three sets, we examine nine different actions and their dependence on both socioeconomic and behavioral characteristics of households as well as on structural dwelling factors. Hence, our quantitative assessment zooms beyond aggregates, acknowledging the fact that various socioeconomic groups may exhibit different behavioral traits for different actions;

(iii) ***Comparative research:*** the two countries in our sample permit us to compare households' choices and the role of behavioral factors across contexts. On the one hand, it allows testing whether behavioral factors included in the theoretical framework matter in different cases, strengthening the validity of the proposed theoretical framework. On the other hand, a comparison across countries accounts for institutional, cultural and climatic factors that do affect households' choices but are often difficult to capture explicitly.

The paper proceeds as follows. The framework underpinning the survey is grounded in psychological theories aimed at understanding individual decision-making (Section 2). Section 3 reports the survey design in the two EU cases. The empirical correlation analysis is complemented by the probit regression model to estimate the main determinants of household energy behavioral change (Section 4). Section 5 discusses the wider policy implications of this study.

2. Theoretical framework

Individual behavior change is a multi-stage process. In application to environmental- and energy-related choices, three behavioral change theories are commonly applied: theory of planned behavior (TPB), norm activation theory (NAT), and value–belief–norm (VBN) theory. TPB, formulated by Ajzen [41] and based on the theory of reasoned action, is one of the most influential theories in social and health psychology and has been used in many environmental studies [12,42]. TPB assumes that an intention to change behavior is shaped by three main factors: human attitude toward a specific behavior, subjective norms, and perceived behavioral control. NAT, originally developed by Schwartz [43], operates in the context of altruistic and environmentally friendly behavior. It is mostly focused on anticipating pride in doing the "right" thing and on studying the evolution of feelings of guilt. VBN theory [44,45] explains environmental behavior and "good intentions" such as willingness to change behavior [25,45,46], environmental citizenship [45], and policy acceptability [47,48]. In summary, TPB focuses on gain goal-frames, while NAT and VBN theories focus on normative goal-frames [25]. Some behavioral factors are common across these alternative conceptualizations of individual pro-environmental choices. While some empirical studies aim to test which of the theories explain choices better, others attempt to combine these theories to offer a more holistic view on individual decision-making [19,49]. We follow the latter approach and introduce a framework that combines the strengths of the three key theories.

Fig. 1 illustrates our conceptual framework that represents household energy behavioral change as a dynamic process unfolding in stages. Knowledge and awareness can have an important role in triggering individual behavior change [23,26,37,38,50–53]. If individuals have enough knowledge and awareness about climate, environment and energy issues, a feeling of guilt may develop and activate motivational factors, which may lead to energy-related behavior change. Motivation is enhanced by personal and social norms [24,54], which can lead to a feeling of responsibility and provoke an individual to change their behavior. When intentions for the latter are high, individuals do a formal feasibility assessment according their income, dwelling conditions and own perceived behavioral control. Individuals compare their current energy-use habits with alternatives, and if things can be improved, the intention to pursue an alternative rises and may lead to a behavior change. This conceptual framework combines some behavioral constructs that are common between TPB (in red) and NAT (in green).

3. Methods

Following the theoretical framework (Fig. 1), we developed a survey to quantify behavioral changes regarding energy use. The latter may

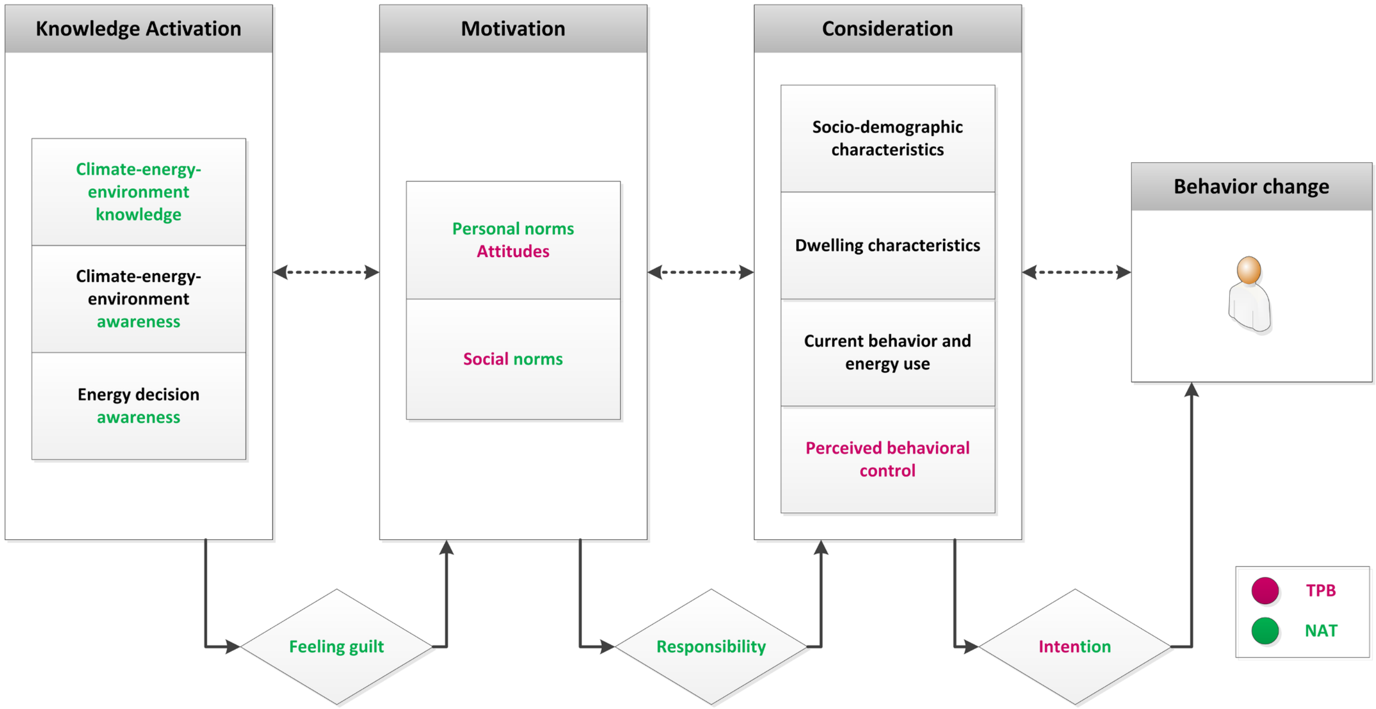


Fig. 1. Conceptual representation of multi-stage household behavioral change.

take different form (see Appendix 1, Table A1.1). Individuals can make investments: either big, such as in solar panels and house insulation, or small, such as in buying energy-efficient appliances [19,55–59]. Alternatively, individuals may save energy by changing their daily routines and habits [13,60–62]. Finally, individuals could switch to a supplier that provides green(er) energy [63–68].

We designed a household survey to capture drivers and barriers in a decision-making process regarding these three types of energy-related actions: investment (I), conservation (C), and switching providers (S). The actions are not mutually exclusive, they can be complementary and the survey aims to understand whether and how many of those are taken up by people. The additional survey questions eliciting economic and behavioral factors affecting these choices permit us to analyze the factors influencing the three types of decisions.

3.1. Questionnaire design

Our questionnaire contains five sections consisting of 55 main questions about sociodemographic characteristic (10), dwelling characteristics (6), energy consumption, behavior and sources (20), personal attitudes and opinion (7), and social networks (12). The questions are designed in different formats based on the type and nature of information required: multiple choice (e.g. for education level, dwelling type, source of energy), Likert-type scale and semantic differential (e.g. for all behavioral factors), dichotomous and open-ended question (e.g. for energy consumption and behavior, and social network). The questionnaire was also translated into Dutch and Spanish, so that respondents can choose their preferred language among three (EN/NL/ES).

While interpreting any survey results (Section 4.1), the possibility of a response bias should be considered. The wording of questions and response scales [19], as well as the respondents' tendency to answer questions untruthfully, particularity for behavioral factors when they may feel pressure to give socially acceptable answers [69], can all contribute to a response bias. To minimize the chance of response bias, our survey took a 3-fold approach by assuring cross-questions, validation by an interdisciplinary team of experts (e.g., psychologist, energy economist, sociologist, governance and policy expert, statistician) and by conducting pilot studies. In particular, to improve the survey quality and feasibility, we performed three pilot studies with: (a) a team of international experts (19 colleagues in the Netherlands and Spain); (b) a small sample of households in Overijssel; (c) a small sample of households in Navarre. The feedback from these pilots was integrated in the final questionnaire to increase its quality and the comprehension of questions by various participants.

3.2. Survey and responses

The final version of questionnaire was used for the large-scale survey and distributed in summer 2016 using the survey infrastructure of Kantar TNS,[2] which is an online multi-language, user-friendly, intelligent and interactive platform. Kantar TNS (formerly known as TNS-NIPO) has many years of experience with carrying out surveys and assuring that a sample of respondents represents a target population. We received 1790 valid completed questionnaires.

We conducted the survey in two provinces in Europe that differ in terms of climate, culture, GDP, technology innovation and diffusion, renewable energy sources, institutional rules, and policies. In summer 2016, 1035 households in the Overijssel province, the Netherlands, and 755 households in the Navarre province, Spain, completed our online questionnaire (Fig. 2).

3.3. Analysis: probit discrete choice model

We assume that households' decisions regarding energy use – *investment* (I), *conservation* (C), and *switching* (S) – are independent of each other and can occur simultaneously. Our survey differentiates between sub-actions within each category. A household may invest in house insulation (I1), install solar panels (I2) or buy energy-efficient appliances (I3). Alternatively, energy use improves by switching off unnecessary devices (C1), turning down the heater / air conditioner (C2) or using less energy by changing daily habits (C3) such as running a

[2] http://www.tnsglobal.com/

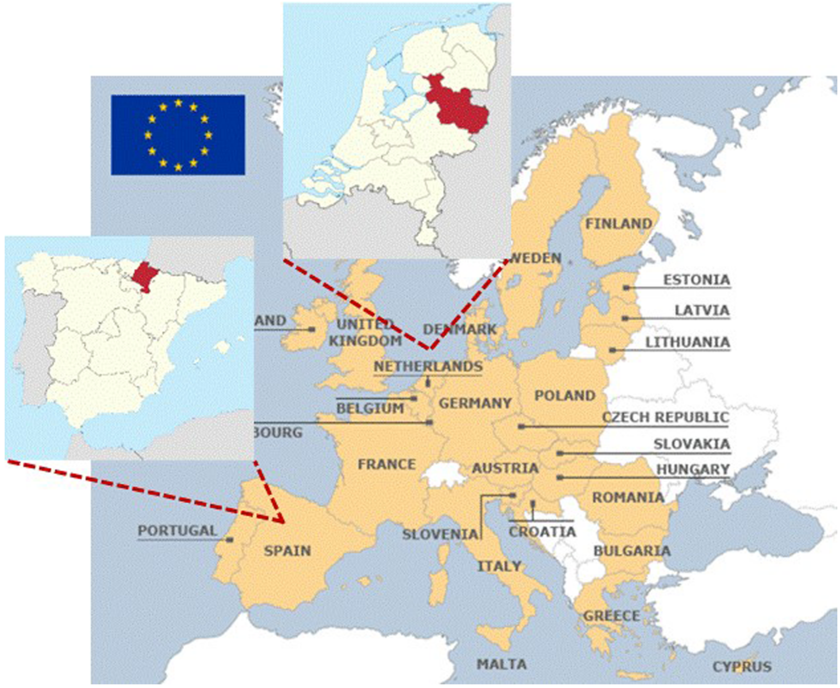


Fig. 2. Survey case studies: the Overijssel province in the Netherlands and the Navarre province in Spain.

full-load washing machine. Lastly, a household may improve its energy footprint by switching to green energy (S1), or switching to another green (S2) or conventional (S3) energy provider. For each of the choices, we developed a statistical model of the household energy decision process based on the discrete "yes" or "no" decisions for the three actions (I, C, S) and their respective sub-actions using a probit regression model [19,30]. The expected utility of each of the sub-options is modeled as follows:

$$y_{ij}^{*} = x_{ij}\beta_i + \varepsilon_{ij} \quad (1)$$

where y_{ij}^{*} is a latent variable that captures the utility of household j associated with its choice to implement sub-option i related to energy investment, energy conservation, or switching (I1–S3). x_{ij} is the vector of explanatory variables, including socioeconomic characteristics of the individuals, dwelling characteristics, energy-use patterns, financial and ownership situation, as well as indicators for personal and social norms. β_i is the parameter vector that needs to be estimated based on the survey data using maximum likelihood econometric methods, and finally, ε_{ij} is the vector of error terms. Individual choice utilities and, hence, preferences of households cannot be observed directly from the survey data and are modeled using the probit discrete choice model decision rule:

$$\begin{aligned} y_{ij} &= 0 \text{if} y_{ij}^{*} < 0 \\ y_{ij} &= 1 \text{if} y_{ij}^{*} \geq 0 \end{aligned} \quad (2)$$

This decision rule means that household j implements a particular sub-action, i (I1–S3), when its expected utility is non-negative, and the household does not implement a particular sub-option when its expected utility is strictly negative (Eq. (2)).

Under the probit discrete choice model, the probability of a household implementing a sub-option (I1–S3) is:

$$P(y_{ij} = 1|_{ij}) = \frac{\exp(x_{ij}\ \beta_i)}{1 +\ \exp(x_{ij}\ \beta_i)} = \Lambda(x_{ij}\ \beta_i) \quad (3)$$

where $\Lambda\,(x_{ij}\beta_i)$ denotes the logistic cumulative distribution function [19].

4. Results and discussion

In addition to presenting the survey descriptive analysis (Section 4.1), we perform the analysis of the survey data to examine the drivers and barriers related to household behavioral change toward a low-carbon economy. Firstly, we check the correlations between the behavioral factors (latent variables) to assess the validity of different items in our theoretical framework and to quantitatively assess the strength of these factors in a decision process (Section 4.2). Secondly, we employ the probit regression analysis to estimate the link between individual household attributes (socioeconomic and behavioral factors) and the likelihood of choosing one of the energy-related actions that contribute to climate change mitigation (Section 4.3).

4.1. Descriptive analysis

Table 1 provides descriptive statistics of the respondents in the two case-study provinces, as well as the corresponding summary statistics on the socio-demographic characteristics of the population in the two provinces.

Tables 2 and 3 provide a brief overview of the descriptive statistics of the respondents, which represent the target population well. This information illustrates the distribution of socio-demographic and dwelling characteristics.

Table 2 shows that our sample is sufficiently gender balanced in both case studies. Respondents in Navarre have a higher education level than in Overijssel, with the majority holding bachelor's or master's degrees. Regarding employment status, the majority of respondents in both cases are employed, followed by retired in Overijssel and unemployed in Navarre. More than half of the respondents in both provinces earn 10–50 thousand euros per year income. Nevertheless, there are more households with an income below 30 thousand euros in the Navarre case. This result may explain why the level of economic comfort in Overijssel is higher compared to Navarre.

The majority of respondents surveyed in Overijssel (85%) live in houses, while 78% of the Navarre respondents live in apartments. Most respondents in both provinces own the place in which they live. The housing stock is generally older in Overijssel than in Navarre. In both

Table 1
Socioeconomic distribution in the region and within the survey sample: Navarre, Spain; Overijssel, the Netherlands Source: Eurostat, 2016 and own survey, 2016.

Factors		Navarre, Spain		Overijssel, the Netherlands	
		Regional	Survey sample	Regional	Survey sample
Population		637,486	755	1134,465	1035
Male population (in percentage)		49%	43%	49.9%	53.6%
Average income (thousand Euro per year)		18	Majority in income group 2 (10–30)	21	Majority in income groups 2 and 3 (10–50)
Education levels (in percentage)	ISCED[a] 0–2	27.9%	16.4%	34.3%	47.8%
	ISCED 3–4	23.2%	22.8%	41.5%	26.6%
	ISCED 5–8	48.8%	60.8%	24.1%	25.6%

[a] "ISCED" stands for "International Standard Classification of Education".

Table 2
Socio-demographic characteristics of surveyed households. Source: own survey.

Socio-demographic items	Overijssel	Navarre
Gender[a]		
female	46.4	57.1
male	53.6	42.9
Age[b]	53	41
Education[a]		
primary (ISCED 0–1)	3.0	2.0
secondary (ISCED 2–3)	49.6	14.4
tertiary (ISCED 4–5)	21.6	22.8
bachelor (ISCED 6)	14.6	26.6
master (ISCED 7)	9.6	30.5
doctorate (ISCED 8)	1.5	3.7
Employment status[a]		
employee (full-time, part-time)	49.9	57.8
self-employed	5.8	9.4
unemployed	5.5	14.2
homemaker (housewife/husband)	6.4	3.2
retired	23.6	5.6
student	2.1	9.1
other	6.6	0.5
Household annual income[a]		
less than ten thousand euros	5.5	11.4
10–30 thousand euros	34.7	46.8
31–50 thousand euros	38.0	27.8
51–70 thousand euros	13.5	8.7
71–90 thousand euros	5.7	3.0
91–110 thousand euros	1.0	0.9
More than 120 thousand euros	1.6	1.3
Level of economic comfort[a,c]		
very difficult to live	7.1	10.2
difficult to live	15.1	20.9
coping	42.3	48.6
living comfortably	29.1	16.2
living very comfortably	6.3	4.2

[a] distribution is reported in percent.
[b] average age is reported.
[c] mean number of people in each household
[c] immediately after getting information on income, respondents were asked about how they 'felt about living on your household's income nowadays (see Appendix 2, Table A2.1).

case studies, the majority of households were not aware of the energy rating of their residence.

Our conceptual framework (Section 2) shows several psychological factors engage in the multi-stages household behavioral change. These factors rooted in psychology theories and empirical studies [12,24,41,43,48,70–74]. Appendix 2 shows how these factors are categorized and measured. Table 4 reports summary statistics on behavioral factors that could affect energy decisions of households. All behavioral factors are measured on a Likert scale of 1–7 (see Appendix 2). The data illustrates that households in both countries have high level of awareness and strong on personal norms that confirm the understanding of the role of individual consumption in climate change. Social norms and perceived behavioral control, which is often associated with financial factors among others, score higher for Spanish respondents compared to the Dutch.

Table 3
Dwelling characteristics in survey sample. Source: own survey.

Dwelling characteristics items	Overijssel	Navarre
Type of residence[a]		
Apartment	14.9	77.8
House	85.1	22.2
Tenure status[a]		
Own the residence	71	80.3
Rent the residence	29	19.7
Size of residence[a]		
Less than 50 m^2	4.5	3.3
50–100 m^2	35.7	62.0
101–150 m^2	35.7	22.4
151–200 m^2	15.2	6.5
More than 200 m^2	8.9	5.8
Age of residence[a]		
Less than five years	4.4	7.2
5–10 years	7.4	22.0
11–20 years	15.8	26.4
21–35 years	26.1	20.9
36–50 years	25.4	14.8
More than 50 years	20.8	8.7
Energy label[a]		
A	15.7	11.7
B	15.9	11.7
C	11.7	7.8
D	4.6	3.7
E	4.6	3.1
F	4.0	1.6
Don't know	43.5	60.3

[a] distribution is reported in percent.

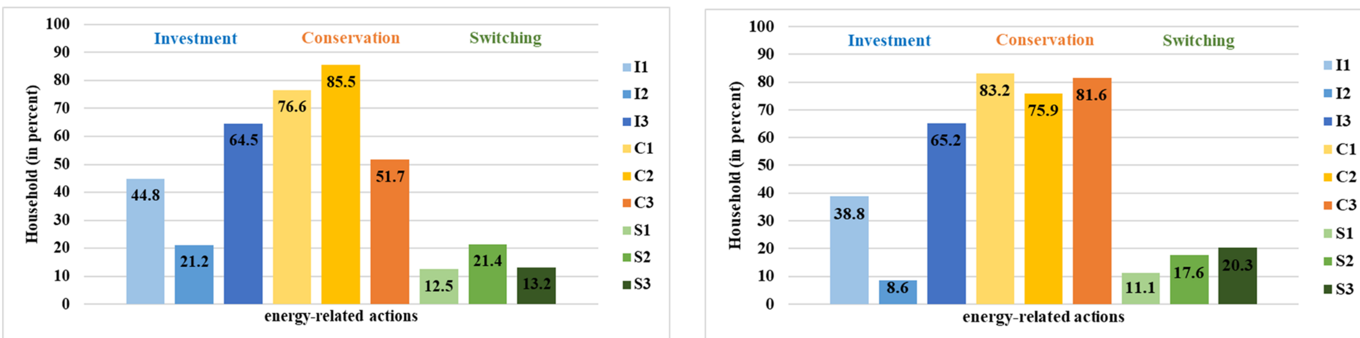
Fig. 3 shows the distribution of energy-related actions, which our survey respondents undertook in the last 10 years. Between 2006–2016 Dutch households were more active in big investments including house insulation (6% more on I1) and solar panels (12.6% more on I2), and in switching to green providers (1.4 – 3.8% more on S1,2) compared to the Spanish respondents. The latter appeared more willing to change habits – 6.6% more respondents in Navarre practice switching off unused devices (C1) and 30% more actively adjust daily household-appliances-use habits (C3) – compared to the Dutch.

4.2. Correlation analysis

Table 5 presents the correlation matrix for the five latent variables representing behavioral factors for the Overijssel (upper triangular matrix) and Navarre (lower triangular matrix) provinces separately. In both cases, all five latent variables correlate positively and substantively. While personal norms (PN) correlate strongly with knowledge (CEEK) and awareness (CEEA, EDA), social norms (SN) have weak positive relationships: the correlation of knowledge and awareness (CEEK, CEEA, EDA) with social norms (SN) is two to three times smaller compared to personal norms (PN). Knowledge and awareness are more tightly connected to social networks for Spanish respondents compared to the Dutch.

Table 4
Scores for behavioral factors among the survey respondents, on a scale from 1–7. Mean (st.dev.) Source: own survey.

Behavioral items		Overijssel	Navarre
Knowledge	Climate–Energy–Economy Knowledge (CEEK)	4.2 (0.7)	5.0 (0.8)
	Climate–Energy–Economy Awareness (CEEA)	4.9 (0.8)	5.4 (0.8)
	Energy Decision Awareness (EDA)	4.5 (1.0)	5.3 (1.1)
Motivation	Personal Norms (PN)	4.6 (0.9)	5.4 (1.0)
	Social Norms (SN)	3.3 (1.1)	4.5 (1.2)
Consideration	Perceived Behavior Control–Investment (PBC1)	4.4 (1.1)	5.0 (0.9)
	Perceived Behavior Control–Conservation (PBC2)	3.5 (1.4)	4.6 (1.4)
	Perceived Behavior Control–Switching (PBC3)	3.4 (1.4)	5.0 (1.3)



(a): Overijssel, the Netherlands   (b): Navarre, Spain

Fig. 3. Shares of survey respondents who undertook energy-related actions in the past 10 years (2006–2016), in%. Here the blue I-group refers to investments (I1 – in house insulation, I2 – in solar panels, I3 – in energy-efficient appliances); the orange C-group refers to conservation due to a change in habits (C1 – switching off unnecessary devices, C2 – moderate inside temperature regulation, C3 – adjusting daily habits such as running a full-load washing machine); the green S-group refers to switching (S1 – to green energy, S2 – switching to another green provider, S3 – to a conventional energy provider). Source: own survey.

Table 5
Correlation of latent constructs (knowledge activation and motivation) for Overijssel (N = 1035, upper triangular matrix) and Navarre (N = 755, lower triangular matrix) Source: own survey.

Variables	CEEK	CEEA	EDA	PN	SN
CEEK	–	0.64	0.49	0.45	0.16
CEEA	0.66	–	0.79	0.71	0.21
EDA	0.53	0.76	–	0.76	0.22
PN	0.52	0.77	0.88	–	0.37
SN	0.27	0.35	0.27	0.40	–

Note: CEEK = climate–energy–economy knowledge; CEEA = climate–energy–economy awareness; EDA = energy-decision awareness; PN = personal norms; SN = social norms.

4.3. *Regression analysis: understanding households' likelihood to pursue individual-level climate change mitigation actions*

Tables 6–8 present the results of the regression analysis using the probit model in STATA 14 for each of the sub-options and include the coefficient levels as well as their p-values. P-values associated with each of the regression parameters β_i indicate whether a particular variable is statistically significant, as well as the level of its statistical significance (see Section 3.3). We consider 1%, 5%, and 10% levels of significance in the interpretation of the probit regression results.

4.3.1. *Factors affecting the probability of a household investing*

We also observe that the country variable (ES vs. NL) has a strong (99% confidence interval) influence on taking a decision to install solar panels. Dutch households are more active in installing photovoltaic solar panels (PVs). Naturally, country-specific fiscal rules, climate change mitigation regulations, culture, and climate may act as drivers or barriers in our two case-study provinces.

Under socio-demographic factors, education has a positive and very significant impact on insulation and PV installation (I1, I2 in Table 6). The probability of taking these actions increases with the level of education (95% confidence interval). Higher economic comfort leads to more investments in appliances (I3, 95% confidence interval). Households seem to be ready to make investments in energy-efficient appliances as soon as they can cope with their other expenses and live comfortably given their income. Also, we observe gender having a very significant (99% confidence interval) impact on installing solar panels (I2), with men being more likely to make this decision than women. Personal norms in regard to environmental issues appear to be very significant in all three investment decisions and have a positive role: a higher level of personal norms leads to more investments (Table 6).

Regarding the characteristics of the residence, we observe that type (apartment vs. house), age, and size have impacts on households' big investment decisions (I1, I2). Type of residence is very significant (99% confidence interval): owners of houses are more eager to install solar panels and invest in insulation. Age of the residence has positive impacts (99% confidence interval) on the likelihood of being insulated. Older buildings tend to be insulated more often as compared to new buildings that already have high energy ratings. However, age has a negative impact (95% confidence interval) on the likelihood of installing solar panels, with more PVs installed on new buildings than on older ones. Size of residence has a positive and significant impact on large investments: owners of larger residences are more likely to invest in PVs or to insulate their houses. The fact that large houses are usually owned by people with higher incomes, and potentially have more energy leakage, makes insulation a priority for their owners among other energy-efficient decisions. Also, larger houses have larger rooftop areas to install PVs. We also found a meaningful correlation between the energy label of residence and investing in insulation (Table 6).

In general, the probability of households' investing is highly correlated with residents' education level (95%), personal norms (90–99%), and type (99%) and size of their residence (90–95%). Hence, personal intentions, knowledge and awareness, and type and size of a house are

Table 6
Probit regressions (PR.I) on investment decisions (I1–I3). Dependent variables: investments in insulation, PV installation, and energy-efficient appliances (N = 1790).

Variables	I1: Insulation coefficients	p-value	I2: PV installation coefficients	p-value	I3: Energy-efficient appliances coefficients	p-value
country	0.1397251	0.1340	−0.4265909	0.0000***	0.047433	0.6110
income	0.0149715	0.6430	−0.0298901	0.4530	−0.0226898	0.4890
gender	0.0795755	0.1980	0.2792288	0.0000***	0.004528	0.9420
education	0.0563284	0.0400**	0.0779388	0.0190**	0.0294806	0.2870
eco-comfort	0.0523404	0.2480	0.0021244	0.9690	0.1059369	0.0210**
age	0.0008106	0.0000***	0.001021	0.0000***	0.0001881	0.2360
tenure	−0.1028189	0.1670	0.0462172	0.6090	−0.0854744	0.2500
energy label	−0.0769971	0.0650*	−0.075806	0.1320	−0.0575989	0.1780
type	0.4265	0.0000***	0.5005143	0.0000***	0.0904679	0.3130
age of residence	0.0883428	0.0000***	−0.0577463	0.0440**	−0.031426	0.1810
size	0.0857047	0.0140**	0.1287344	0.0010***	0.0510185	0.1530
electricity	0.0000182	0.3820	−0.0000937	0.0000***	0.0000697	0.0010***
gas	0.0000488	0.0480**	0.0000127	0.6980	0.000008	0.7500
personal norms	0.052849	0.1000*	0.082771	0.0350**	0.095038	0.0030***
social norms	0.0020971	0.9330	0.003869	0.9000	−0.0161594	0.5160

Note: * refers to 10% significance level, ** refers to 5% significance level, and *** refers to 1% significance level.

core in promoting energy-efficient investments among households.

4.3.2. Factors affecting the probability of a household conserving energy

Energy conservation actions (C1–C3) correlate significantly with the country (Table 7). Specifically, Spanish households are more active in switching off unnecessary devices (C1, 99% confidence interval) and using less energy (C3, 99% confidence interval), while Dutch households are more likely to reduce their use of the heater / air conditioner (C2, 99% confidence interval).

Analysis of socio-demographic factors highlights the roles of gender and economic comfort. Gender bias is observed under C2 and C3 decisions: women pursue more energy conservation compared to men. Moreover, we detect that households not satisfied with their current economic situation are more likely to try to save money by reducing their energy bill and switching off unnecessary devices (economic comfort, 95% confidence interval). Personal norms appear very significant and positive (99% confidence interval) for all three conservation actions.

Type and energy label of residence emerge as important factors in conserving on heating/cooling (C2): people living in houses are more likely turn down the heating compared to people living in apartments. The worse the energy label, the higher the energy leakage and the more people try to conserve their energy use by reducing heating/cooling. Consequently, residences with low energy labels potentially have more energy leakage leading to growth in energy consumption and bills. To save energy and money, households either should invest in insulation (Table 6) or save energy by turning down the heating/cooling system and adapting to less comfortable temperatures.

In summary, the likelihood of households conserving energy (C1–C3) correlates with personal norms and the type, energy label, and age of their residences.

4.3.3. Factors affecting the probability of a household switching energy providers

Switching to another green provider (S2) correlates significantly with the country (Table 8,%99). This result could reflect greater market competition between providers in Netherlands.

Education plays an important role in the transition to green energies (S1, S2): households with higher levels of education are more likely to switch (95% confidence interval). In addition, this is the only place where we capture the correlation between income and household decisions (S3): lower income groups are more likely to switch to conventional providers. This result can be explained by these households seeking lower costs, which are still found with conventional energy providers. Personal norms appear significant (95% confidence interval) for switching to another green energy provider: households switching to greener energy have higher personal norms.

Regarding the residence characteristics, age and energy rating come out as important. Owners of older buildings are more likely to switch to another green provider (99% confidence interval). Residences with a

Table 7
Probit regression conservation (PR.II). Dependent variables: switching off devices when not in use, turning down the heater / air conditioner and generally using less energy (N = 1790).

Variables	C1: Switch off or unplug devices when not in use coefficients	p-value	C2: Turn down the heater / air conditioner coefficients	p-value	C3: Use less energy coefficients	p-value
country	0.2706158	0.0080***	−0.3943574	0.0000***	0.7156096	0.0000***
income	−0.0427815	0.2340	−0.0076126	0.8400	−0.0591228	0.0800*
gender	−0.0125411	0.8560	−0.1723292	0.0160**	−0.2067435	0.0010***
education	−0.0233181	0.4430	0.0272647	0.3920	0.0256838	0.3710
eco-comfort	0.1049109	0.0340**	−0.0567201	0.2740	−0.0145656	0.7560
age	0.0001355	0.4290	−0.0004648	0.0090***	0.0002276	0.1630
tenure	−0.0457255	0.5770	−0.1251689	0.1390	−0.0582215	0.4490
energy label	0.0587441	0.2060	0.0965134	0.0490**	0.0124117	0.7750
type	0.1060117	0.2780	0.3023552	0.0030***	0.0322179	0.7290
age of residence	−0.0009385	0.9710	−0.0716471	0.0070***	0.0019361	0.9370
size	0.0169433	0.6630	−0.0368238	0.3740	0.007845	0.8280
electricity	0.000021	0.3680	−0.0000	0.9130	0.0000149	0.4950
gas	−0.000005	0.8500	0.0000819	0.0060***	0.0000161	0.5540
personal norms	0.1134906	0.0010***	0.1534471	0.0000***	0.1619213	0.0000***
social norms	0.0108234	0.6950	−0.0547073	0.0590*	0.0261578	0.3130

Note: * refers to 10% significance level, ** refers to 5% significance level, and *** refers to 1% significance level.

Table 8
Probit regression on switching (PR.III). Dependent variables: switching supplier – from gray to green, from green to another green, from Gray to another conventional provider (*N* = 1790).

Variables	S1: Switch to green energy		S2: Switch to another green energy provider		S3: Switch to another conventional provider	
	coefficients	p-value	coefficients	p-value	coefficients	p-value
country	−0.1739922	0.1430	−0.2817241	0.0070***	0.1780758	0.1020*
income	0.0379236	0.3540	−0.0410168	0.2680	−0.0634739	0.1070*
gender	0.0833157	0.2960	0.0357666	0.6080	0.0819696	0.2660
education	0.0856276	0.0130**	0.0639826	0.0380**	0.0266516	0.4050
eco-comfort	0.016136	0.7710	0.0036614	0.9430	−0.021244	0.6960
age	0.0010655	0.0000***	0.0006837	0.0000***	0.0005574	0.0030***
tenure	0.073537	0.4340	−0.0470855	0.5730	−0.026532	0.7630
energy label	−0.0974067	0.0730*	0.0245303	0.5980	0.0700238	0.1560
type	0.0618649	0.5900	0.0194978	0.8460	−0.0912484	0.3910
age of residence	0.0129401	0.6650	−0.0869868	0.0010***	−0.0172708	0.5280
size	0.0529026	0.2340	0.059853	0.1280	0.0601634	0.1510
electricity	−0.0000671	0.0140**	0.0000291	0.2200	0.0000	0.9820
gas	0.0000112	0.7320	−0.0000382	0.1850	0.0001035	0.0000***
personal norms	0.0648121	0.1180	0.080775	0.0290**	−0.0434834	0.2560
social norms	0.0450193	0.1620	0.0355918	0.2090	−0.0095217	0.7500

Note: * refers to 10% significance level, ** refers to 5% significance level, and *** refers to 1% significance level.

lower energy label rating tend to switch to a green provider (95% confidence interval).

The decisions to switch to a green provider (S1) and from one green provider to another (S2) tend to have quite similar types of explanatory variables. However, in switching to another green provider, personal norms play an important role.

4.3.4. Predicted probabilities of individual actions

To follow the socio-demographic, structural, and behavioral factors' magnitudes, we tested the marginal effect across a range of their values (Section 3.3). Among all factors, personal norms and education demonstrated significant results. Also, the regression analysis (Sections 4.3.1–4.3.3) unanimously showed the importance of these two factors. Fig. 4 illustrates the effect of personal norms and education levels on nine household behaviors (I1–3, C1–3, S1–3).

A higher level of personal norms increases the probability of energy investments (I1–3, blue lines), conservation (C1–3, orange lines), and switching to green providers (S1 and S2, green lines), in contrast to switching to another conventional supplier (S3, light green line). This result clearly shows that an increase in the level of personal norms leads to a large increase in the probabilities of transition to a low-carbon economy.

4.4. Limitations

It should be noted there is a chance of social-desirability bias in social science research. This bias comes from over reporting a good behaviour. There is a tendency of respondents to answer questions in a manner that will be viewed favorably by others. However, we minimized self-reported bias by carefully design and validate questions one by one and as a set of questions, and also using skills and experiences of a survey company team in validating and conducting this survey (Section 3.1 and 3.2).

In this research we focused on households energy use at home (electricity and heating/cooling). It might be interesting to look at the full household footprint shaped by energy use at home, dietary choices

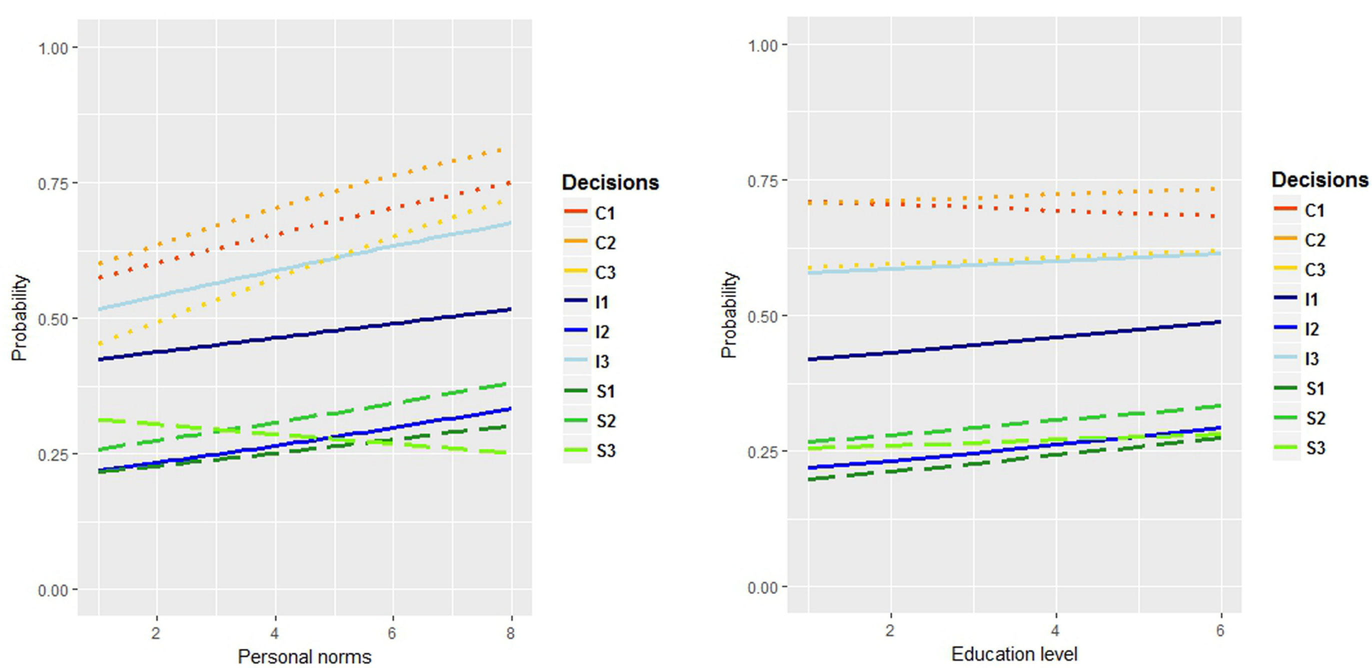


Fig. 4. Predicted probability of energy-related actions (I1–S3) depending on personal norms and education level.

and transportation modes preferred by people. However, the latter two are entirely different types of choices and both well studied in the respective scientific communities. For example, transportation choice is contingent on the availability of public infrastructure, location of jobs relative to individual residences, and frequency of commute either for work or for leisure [13,16,105–107]. Food choices may be contingent on rigid cultural traditions as well as availability of non-meat based options. Therefore, individual factors shaping transportation and dietary choices are likely to be different compared to households' energy use, which make it difficult to study within one survey in depth.

5. Conclusions and policy implications

This article offers a strong evidence of the importance of behavioral factors in making energy-related decisions and in promoting behavioral solutions for climate change mitigation in Europe. We develop a conceptual framework rooted in behavioral theories from psychology and designed a questionnaire based on it. By using our survey data we quantitatively investigate the relevance of behavioral factors in this framework (Section 4.2). Several behavioral factors (e.g., knowledge and awareness) influence personal norms: the higher the level of knowledge and awareness about environmental and climate issues, the higher the level of personal norms. The impact of societal institutional rules – cultural, fiscal, and regulatory – on individuals is inevitable, as confirmed by the significant difference between the two countries analyzed. Moreover, households are not making decisions in isolation: they are prone to the influence of interactions with peers in their social networks. In fact, social norms have an essential role in shaping individual decisions [75-77]. Together, personal and social norms can drive individuals to make energy-efficient decisions. Literature also indicates that behavioural factors are positively related to household energy use and conservation [35,70,78], willingness to switch to green (er) provider [79], and other pro-environmental behaviors such as recycling and fuel conservation [80]. Bamberg and Möser in their meta-analysis found a relatively strong correlation between social norms and pro-environmental behavior ($r = 0.31$), as well as personal norms and pro-environmental behavior ($r = 0.39$)[53]. Chen et al. study low-income households energy conservations intentions and conclude households behavioral factor such as personal attitude and social norms have a positive impact (99% confidence interval) on energy-conservation (C) decisions [35].

We quantitatively assess nine different energy-related actions and their dependence not only on behavioral factors but also on socio-demographic and structural dwelling factors. Among dwelling characteristics, the type, size, and age of the residence have a strong influence on energy investments and conservation. As expected, people living in houses, compared to those in apartments, are more eager to pursue large investments and have an extra incentive to save energy by turning down the heater / air conditioner. The findings of earlier studies also confirm that dwelling characteristics such as size, type and age of residence are important determinants for the homeowners' energy decisions [20,28,30,31,81-84]. Nair et al. in their study of Swedish residential buildings found that owners of older houses may be more inclined to adopt because old houses may be in physically or aesthetically poor condition, requiring the installation of new building envelope components [81]. Heinonen and Junnila demonstrated while on a household level the detached housing appears to be by far the most energy intensive, the differences are greatly reduced when the differences in household sizes are taken into account [84].

Analysis of socio-demographic factors highlights the role of education in household energy-related decisions, particularly in energy investments and in switching to green energy sources. Educated households are more active in improving their energy efficiency in both case studies. A higher level of education enables more insight, knowledge, and awareness of environment–climate–energy issues, which all consequently affect personal norms and lead to behavior change. While majority of studies in the literature, confirm the positive impact of education on household's pro-environmental decision [20,21,28,30,31,81,85–89], there are a few exceptions, which reported education has no significant impact on particular energy-related behavior, e.g. light bulb replacement choices [19,90,91].

The comparative analysis between two countries allows us to validate the conceptual framework by testing the relation of behavioral factors across contexts (Section 4.2). The country dummy serves as a proxy to capture to what extent differences in institutional, cultural and climatic factors affect households' energy choices. Namely, our analysis shows that Dutch households are more active in investing in house insulation (I1) and in installing PVs (I2). However, Spanish households pioneer in energy conservation by changing daily habits (C1, C3). We also find that switching to another green provider (S2) correlates significantly with the country which could reflect greater market competition between green providers in Netherlands. The importance of spatial and geographical location is strongly acknowledged in the literature [19,21,31,35,60,81,92]. Mill highlights a great deal of country heterogeneity in household energy-efficient technology adoption, energy conservation practices, and attitudes towards energy savings [21]. Chen et al. analyzed several cities in five climate zones in China and found that space cooling equipment is more widely used in Hong Kong, Shanghai, and Changsha due to the high outdoor temperature and much more electricity is used consequently [92]. She proved this hypothesis later in another empirical study [35]. Nair et al. argue geographical location may influence homeowners' preference towards energy actions due to the influence of the local governments' activities to promote energy efficiency measures [81].

While policies potentially act as an important external (top-down) driver/barrier in households' energy decision-making in climate-energy studies, the role and influence of bottom-up drivers such as household sociodemographic characteristics, their structural and psychological factors in climate change mitigation movements are inevitable. To conclude, our research empirically investigates the bottom-up drivers and barriers behind households' energy use choices and clearly demonstrates that behavioral factors, next to structural factors and education, play at least as important a role in energy decisions as monetary factors such as income. This result has implications for the type of governmental regulations and policies that can be implemented to facilitate the green energy transition. In particular, policies such as the provision of targeted information and social advertisements for the broader public in combination with education to create more knowledge and awareness in the longer run could accompany and reinforce the effectiveness of other stimuli such as subsidies. Including special topics in educational programs can help to change the level of understanding, awareness, and individual norms of households. These so-called nudging or soft policy measures may prove more effective in promoting green energy solutions implemented by households compared to fiscal policy measures alone. In addition, series of regulation and policy can be implemented to support infrastructure development and overcome physical barriers. Particularly, policies and regulation to support local initiatives and collective investments in order to provide opportunities for renters or people who lives in apartment to invest on green energies as well. Therefore, a variety of policy instruments should be used with combinations of various financial, social, and other instruments in the policy mix complementing and reinforcing each other.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1

Table A1.1
Overview of energy behaviors in the housing sector.

households energy behaviors *Investment*	Empirical evidence
■ Installing a solar power system ■ Installing thermal solar power system ■ Insulation: roof, floor, wall, … ■ Installing efficient appliances ■ Installing smart meters	Mohandes, Sanfilippo [55]; Abdmouleh, Gastli [59]; Cabeza, Ürge-Vorsatz [93]; Seebauer [57]; Deng and Newton [94]; Buchanan, Banks [58]; Rai and Henry [18]; Buryk, Mead [95]; Ameli and Brandt [19]; Rai and Robinson [56]; Tran [68]; Chappin, Dijkema [96]
Energy conservation	
■ Turn off extra devices ■ Consciously use less electricity ■ Run only full load washing machines ■ Tolerate lower (higher) temperature in winter (summer)	Hess, Samuel [29]; Jia, Xu [97]; Nakano, Zusman [98]; Rosenow, Guertler [99]; Thøgersen [100]; Thøgersen [101]; Amouroux, Huraux [102]; Faber, Schoroten [62]; Mills and Schleich [21]
Switching supplier	
■ Switch from conventional to a green supplier ■ Switch to greener supplier	Katz, Kitzing [63]; He and Reiner [64]; Rommel, Sagebiel [66]; Yang [65]; McDaniel and Groothuis [67]; Tran [68]

Appendix 2

Following Tables A2.2-4, in complementation of Table 4, show what is the main behavioral items in multi-stage household decision-making process -knowledge activation, motivation, and consideration- and how we measured each of these items. All items measured on a 7 score Likert scale. To measure each of these items we rely following questions, inspired by the standard measures used in the behavioral literature.

Knowledge is measured as a combination of the three main items: Climate–Energy–Economy Knowledge (CEEK), Climate–Energy–Economy Awareness (CEEA), and Energy Decision Awareness (EDA) (see Fig. 1). Table A2.2 shows example questions of each knowledge activation items.

Table A2.1
Items of socio-demographic characteristics. Source: own survey.

Household socio-demographic characteristics

Employment status

What is your current employment status?

○ Employee (full time, part time or on temporary leave)
○ Self-employed
○ Unemployed / Seeking a job
○ Homemaker-Housewife/husband (doing housework, e.g. looking after children)
○ Retired
○ Student
○ Other, please specify: _________

Household annual income

What is your total household's approximate annual income, after tax?

Please include income from everyone in your household from all sources, including wages, government pensions and benefits and investments:

○ Less than Euro 10 000
○ Euro 10 000- Euro 30 000
○ Euro 30 001- Euro 50 000
○ Euro 50 001- Euro 70 000
○ Euro 70 001- Euro 90 000
○ Euro 90 001- Euro 110 000
○ More than Euro 110 000

Level of economic comfort

Which of the following descriptions is closest to how you feel about living on your household's income nowadays?

○ Finding it very difficult to live on current income
○ Finding it difficult to live on current income
○ Coping on current income
○ Living comfortably on current income
○ Living very comfortably on current income

Table A2.2
Items of psychological factors, "Knowledge". Source: own survey.

Knowledge
Climate-Energy-Economy Knowledge
Climate change is caused by a hole in the earth's atmosphere.
Climate change issues should be dealt with primarily by future generations.
Climate-Energy-Economy Awareness
I believe that ….
the effect of environmental issues on human health is worse than we realize.
environmental issues, even in one region, affect other regions.
environmental impacts are frequently overstated.
environmental issues like climate change is caused by our use of fossil fuels.
protecting the environment is a means of stimulating economic growth.
nature is fragile and if we don't take care of it properly, it could destabilize.
Energy Decision Awareness
I believe that my energy source choice (renewables or fossil fuels) has an impact on the environment.
I think avoiding fossil fuels use will help solve wider environmental issues.

all items measured with Likert scales with labelled end-points (1 = "totally disagree" and 7 = "totally agree").

Table A2.3
Items of psychological factors, "Motivation". Source: own survey.

Motivation
*Personal Norms**
I believe that….
the effect of environmental issues on human health is worse than we realize.
I can help solve environmental, climate and energy problems.
when I use fossil fuels, there are greenhouse gasses emitted which threaten human health.
every time we use coal, oil or gas, we contribute to climate change.
Reducing my energy consumption is a personal willingness and self-motivation
*Social Norms***
I will reduce my energy consumption if …
more practical information on how to reduce energy consumption at home
funding out that my households uses more energy than similar households
public labels which neighbors can see
encouragement or actions of friends and family
encouragement or actions of group/associations that I am part of them
Governmental policies and subsidies (i.e. municipalities, provincial, national level)

* all items measured with Likert scales with labelled end-points (1 = "totally disagree" and 7 = "totally agree").
** all items measured with Likert scales with labelled end-points (1 = "not important" and 7 = "very important").

Table A2.4
Items of psychological factors, "Consideration". Source: own survey, 2016.

Consideration
Perceived Behavior Control-investment (PBC1)
I would reduce my energy consumption, if more practical information on how I can invest in green energies (e.g. install solar panels) would be available.
If there were subsidies I would produce part of my green energy consumption (e.g. install solar panel or fund a wind turbine).
Perceived Behavior Control-Conservation (PBC2)
I would reduce my energy consumption if energy prices would be higher.
I would reduce my energy consumption, if more practical information on how to reduce energy consumption at home would be available.
Perceived Behavior Control-Switching (PBC3)
If I had enough information, it would be easier to switch to green energy
If a renewable/green energy tariff was available at another energy provider, I would change my provider.
If a better/cheaper offer was available at another energy provider, I would change my provider.

all items measured with Likert scales with labelled end-points (1 = "totally disagree" and 7 = "totally agree").

Please note there are several statements are scientifically correct to "disagree" and this is carefully considered during analysis (swap the scores). Table 4 reports mean and standard deviation these items among the survey respondents in both case studies.

Motivation is consist of Personal norms (PN) and Social norms (SN) psychological factors. Personal norms are attached to the self-concept and experienced as feelings of a moral obligation to perform a certain behavior [24,41,43, 73, 103]; while Social norms are determined by the perceived social pressure from others for an individual to behave in a certain manner and their motivation to comply with those people's views [24,75,77,104]. Table A2.3 brings example questions that we asked to measure PN and SN. The main psychological factor of the consideration stage is perceived behavior control (see Fig. 1) which is differ in three actions (PBC1, PBC2, PBC3). PBC is refer to own perception of her ability to perform an action or change behavior [24,54,103]. Table A2.4 shows example questions that we asked households to measure their PBC based on three actions.

References

[1] F. Creutzig, J. Roy, W.F. Lamb, I.M.L. Azevedo, W. Bruine de Bruin, H. Dalkmann, et al., Towards demand-side solutions for mitigating climate change, Nat. Clim. Change 8 (2018) 268–271.
[2] L. Niamir, G. Kiesewetter, F. Wagner, W. Schöpp, T. Filatova, A. Voinov, et al., Assessing the macroeconomic impacts of individual behavioral changes on carbon emissions, Climatic Change (2019) 1–20, https://doi.org/10.1007/s10584-019-02566-8.
[3] E.G. Hertwich, G.P. Peters, Carbon footprint of nations: a global, trade-linked analysis, Environ. Sci. Technol. 43 (2009) 6414–6420.
[4] IPCC. Summary for Policymakers, Global Warming of 1.5°C, in: V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (Eds.), An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, 2018, p. 32 the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.
[5] R.K. Pachauri, L.A. Meyer (Eds.), IPCC, Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core, Writing Team, IPCC, Geneva, Switzerland, 2014, p. 151.
[6] N. Oreskes, The scientific consensus on climate change, Science 306 (2004) 1686.
[7] G. Baiocchi, J. Minx, K Hubacek, The impact of social factors and consumer behavior on carbon dioxide emissions in the united kingdom, J. Ind. Ecol 14 (2010) 50–72.
[8] R. Umit, W. Poortinga, P. Jokinen, P Pohjolainen, The role of income in energy efficiency and curtailment behaviours: findings from 22 european countries, Energy Res. Soc. Sci. 53 (2019) 206–214.
[9] E. van der Werff, L Steg, One model to predict them all: predicting energy behaviours with the norm activation model, Energy Res. Soc. Sci. 6 (2015) 8–14.
[10] E. van der Werff, D. Taufik, L Venhoeven, Pull the plug: how private commitment strategies can strengthen personal norms and promote energy-saving in the netherlands, Energy Res. Soc. Sci. 54 (2019) 26–33.
[11] A.M. Peters, E. van der Werff, L Steg, Beyond purchasing: electric vehicle adoption motivation and consistent sustainable energy behaviour in the Netherlands, Energy Res. Soc. Sci. 39 (2018) 234–247.
[12] M.C. Onwezen, G. Antonides, J Bartels, The norm activation model: an exploration of the functions of anticipated pride and guilt in pro-environmental behaviour, J. Econ. Psychol. 39 (2013) 141–153.
[13] G. Dubois, B. Sovacool, C. Aall, M. Nilsson, C. Barbier, A. Herrmann, et al., It starts at home? climate policies targeting household consumption and behavioral decisions are key to low-carbon futures, Energy Res. Soc. Sci 52 (2019) 144–158.
[14] D. Li, X. Xu, C.F. Chen, C Menassa, Understanding energy-saving behaviors in the American workplace: a unified theory of motivation, opportunity, and ability, Energy Res. Social Sci. 51 (2019) 198–209.
[15] IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In: Pachauri R.K., Meyer L.A., Eds.. Geneva, Switzerland2014. p. 151.
[16] F. Creutzig, B. Fernandez, H. Haberl, R. Khosla, Y. Mulugetta, K.C Seto, Beyond technology: demand-Side solutions for climate change mitigation, Annu. Rev. Environ Resour. 41 (41) (2016) 173–198.
[17] P.C. Stern, K.B. Janda, M.A. Brown, L. Steg, E.L. Vine, L Lutzenhiser, Opportunities and insights for reducing fossil fuel consumption by households and organizations, Nat. Energy 1 (2016).
[18] V. Rai, A.D. Henry, Agent-based modelling of consumer energy choices, Nat. Clim Change 6 (2016) 556–562.
[19] N. Ameli, N. Brandt, Determinants of households' investment in energy efficiency and renewables: evidence from the Oecd survey on household environmental behaviour and attitudes, Environ Res. Lett. 10 (2015).
[20] B.F. Mills, J. Schleich, Profits or preferences? assessing the adoption of residential solar thermal technologies, Energ Policy 37 (2009) 4145–4154.
[21] B. Mills, Schleich, J. Residential, energy-efficient technology adoption, energy conservation, knowledge, and attitudes: an analysis of european countries, Energ Policy 49 (2012) 616–628.
[22] R. Li, G. Dane, C. Finck, W Zeiler, Are building users prepared for energy flexible buildings?—A large-scale survey in the netherlands, Appl. Energ 203 (2017) 623–634.
[23] C.B.A. Kobus, E.A.M. Klaassen, R. Mugge, J.P.L Schoormans, A real-life assessment on the effect of smart appliances for shifting households' electricity demand, Appl. Energ 147 (2015) 335–343.
[24] S. Bamberg, M. Hunecke, A Blobaum, Social context, personal norms and the use of public transportation: two field studies, J. Environ. Psychol 27 (2007) 190–203.
[25] L. Steg, C Vlek, Encouraging pro-environmental behaviour: an integrative review and research agenda, J. Environ Psychol 29 (2009) 309–317.
[26] I. Vassileva, E. Dahlquist, F. Wallin, J Campillo, Energy consumption feedback devices' impact evaluation on domestic energy use, Appl. Energ 106 (2013) 314–320.
[27] C. Long, B.F. Mills, J Schleich, Characteristics or culture? determinants of household energy use behavior in Germany and the USA, Energ Effic. 11 (2018) 777–798.
[28] E. Sardianou, P. Genoudi, Which factors affect the willingness of consumers to adopt renewable energies? Renew Energ 57 (2013) 1–4.
[29] A.K. Hess, R. Samuel, P Burger, Informing a social practice theory framework with social-psychological factors for analyzing routinized energy consumption: a multivariate analysis of three practices, Energy Res. Social Sci. 46 (2018) 183–193.
[30] B. Mills, J Schleich, What's driving energy efficient appliance label awareness and purchase propensity? Energ Pol. 38 (2010) 814–825.
[31] C.C. Michelsen, R. Madlener, Homeowners ' preferences for adopting innovative residential heating systems: a discrete choice analysis for germany, Energ Econ. 34 (2012) 1271–1283.
[32] K. Mahapatra, L. Gustavsson, An adopter-centric approach to analyze the diffusion patterns of innovative residential heating systems in sweden, Energ Pol. 36 (2008) 577–590.
[33] Davis L.W.Evaluating the slow adoption of energy efficient investments: are renters less likely to have energy efficient appliances?National Bureau of Economic Research Working Paper Series. 2010;No. 16114.
[34] K. Gillingham, M. Harding, D Rapson, Split incentives in residential energy consumption, Energy J. 33 (2012).
[35] C.F. Chen, X. Xu, J.K Day, Thermal comfort or money saving? exploring intentions to conserve energy among low-income households in the united states, Energy Res. Soc. Sci. 26 (2017) 61–71.
[36] I.G. Hamilton, P.J. Steadman, H. Bruhns, A.J. Summerfield, R Lowe, Energy efficiency in the british housing stock: energy demand and the homes energy efficiency database, Energ Pol. 60 (2013) 462–480.
[37] C. Wilson, H. Pettifor, G Chryssochoidis, Quantitative modelling of why and how homeowners decide to renovate energy efficiently, Appl. Energy 212 (2018) 1333–1344.
[38] K. Matsui, H. Ochiai, Y Yamagata, Feedback on electricity usage for home energy management: a social experiment in a local village of cold region, Appl. Energ 120 (2014) 159–168.
[39] E.J. Hutchinson, P. Wilkinson, S.H. Hong, T Oreszczyn, Can we improve the identification of cold homes for targeted home energy-efficiency improvements? Appl. Energ 83 (2006) 1198–1209.
[40] E.R. Frederiks, K. Stennerl, E.V Hobman, Household energy use: applying behavioural economics to understand consumer decision-making and behaviour, Renew Sust. Energ Rev 41 (2015) 1385–1394.
[41] I Ajzen, Understanding Attitudes and Predicting Social Behavior. Englewood, in: N.J Cliffs (Ed.), Prentice-Hall, 1980.
[42] C.J. Armitage, M. Conner, Efficacy of the theory of planned behaviour: a meta-analytic review, Brit J. Soc. Psychol 40 (2001) 471–499.
[43] S.H. Schwartz, Normative influences on altruism1, in: B Leonard (Ed.), Advances in Experimental Social Psychology, Academic Press, 1977, pp. 221–279.
[44] P.C. Stern, Toward a coherent theory of environmentally significant behavior, J. Soc. Issues 56 (2000) 407–424.
[45] P.C. Stern, T. Dietz, T. Abel, G.A. Guagnano, L Kalof, A value-belief-norm theory of support for social movements, Hum Ecol. Rev 6 (1999) 81–97.
[46] A.M. Nordlund, J. Garvill, Effects of values, problem awareness, and personal norm on willingness to reduce personal car use, J. Environ. Psychol 23 (2003) 339–347.
[47] L. Steg, L. Dreijerink, W Abrahamse, Factors influencing the acceptability of energy policies: a test of vbn theory, J. Environ Psychol 25 (2005) 415–425.
[48] J.I.M. De Groot, L Steg, Morality and prosocial behavior: the role of awareness, responsibility, and norms in the norm activation model, J. Soc. Psychol 149 (2009) 425–449.
[49] S. Bamberg, J. Rees, S Seebauer, Collective climate action: determinants of participation intention in community-based pro-environmental initiatives, J. Environ Psychol 43 (2015) 155–165.
[50] L. Niamir, T Filatova, From climate change awareness to energy efficient behaviour, Proceedings of the 8th International Congress on Environmental Modelling and Software, Toulouse, France, 2016.
[51] L. Niamir, T. Filatova, A. Voinov, H Bressers, Transition to low-carbon economy: assessing cumulative impacts of individual behavioral changes, Energ Pol. 118 (2018) 325–345.
[52] A. Desa, Kadir NByA, F Yusooff, A study on the knowledge, attitudes, awareness status and behaviour concerning solid waste management, Proced. Social Behav. Sci. 18 (2011) 643–648.
[53] S. Bamberg, Moser, G. Twenty, years after hines, hungerford, and tomera: a new meta-analysis of psycho-social determinants of pro-environmental behaviour, J. Environ Psychol 27 (2007) 14–25.
[54] W. Abrahamse, L Steg, How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? J. Econ. Psychol 30 (2009) 711–720.
[55] N. Mohandes, A. Sanfilippo, M Al Fakhri, Modeling residential adoption of solar energy in the arabian Gulf region, Renew Energy 131 (2019) 381–389.
[56] V. Rai, S.A. Robinson, Agent-based modeling of energy technology adoption: empirical integration of social, behavioral, economic, and environmental factors,

Environ Modell. Softw 70 (2015) 163–177.
[57] S. Seebauer, The psychology of rebound effects: explaining energy efficiency rebound behaviours with electric vehicles and building insulation in austria, Energy Res. Soc. Sci. 46 (2018) 311–320.
[58] K. Buchanan, N. Banks, I. Preston, R Russo, The british public's perception of the uk smart metering initiative: threats and opportunities, Energ Pol. 91 (2016) 87–97.
[59] Z. Abdmouleh, A. Gastli, L Ben-Brahim, Survey about public perception regarding smart grid, energy efficiency & renewable energies applications in qatar, Renew. Susta/ Energy Rev. 82 (2018) 168–175.
[60] A.-.K. Hess, R. Samuel, P Burger, Informing a social practice theory framework with social-psychological factors for analyzing routinized energy consumption: a multivariate analysis of three practices, Energy Res. Soc. Sci. 46 (2018) 183–193.
[61] J. Thogersen, F. Olander, Spillover of environment-friendly consumer behaviour, J. Environ Psychol 23 (2003) 225–236.
[62] Faber J., Schoroten A., Bles M., Sevenster M., Markowska A., Smit M., et al. Behavioural climate change mitigation options and their appropriate inclusion in quantitative longer term policy scenarios. Delft2012.
[63] J. Katz, L. Kitzing, S.T. Schröder, F.M. Andersen, P.E. Morthorst, M Stryg, Household electricity consumers' incentive to choose dynamic pricing under different taxation schemes, Wiley Interdisci. Rev. Energy Environ 7 (2018).
[64] X. He, D Reiner, Why consumers switch energy suppliers: the role of individual attitudes, Energ J 38 (2017) 25–53.
[65] Y. Yang, Understanding household switching behavior in the retail electricity market, Energ Pol. 69 (2014) 406–414.
[66] J. Rommel, J. Sagebiel, J.R Müller, Quality uncertainty and the market for renewable energy: evidence from German consumers, Renew Energ 94 (2016) 106–113.
[67] T.M. McDaniel, P.A. Groothuis, Retail competition in electricity supply-Survey results in North Carolina, Energ Policy 48 (2012) 315–321.
[68] M. Tran, Agent-behaviour and network influence on energy innovation diffusion, Commun. Nonlinear Sci. 17 (2012) 3682–3695.
[69] S.I. Donaldson, E.J. Grant-Vallone, Understanding self-report bias in organizational behavior research, J. Bus Psychol 17 (2002) 245–260.
[70] W. Abrahamse, L Steg, Factors related to household energy use and intention to reduce it: the role of psychological and socio-demographic variables, Hum Ecol Rev 18 (2011) 30–40.
[71] R. Wall, P. Devine-Wright, G.A Mill, Comparing and combining theories to explain proenvironmental intentions - The case of commuting-mode choice, Environ Behav 39 (2007) 731–753.
[72] Steg L. Values, Norms, and intrinsic motivation to act proenvironmentally, Annu. Rev. Environ Resour. 41 (41) (2016) 277–292.
[73] N.M.A. Huijts, E.J.E. Molin, L Steg, Psychological factors influencing sustainable energy technology acceptance: a review-based comprehensive framework, Renew Sust. Energ Rev 16 (2012) 525–531.
[74] E. van der Werff, L Steg, The psychology of participation and interest in smart energy systems: comparing the value-belief-norm theory and the value-identity-personal norm model, Energy Res. Social Sci. 22 (2016) 107–114.
[75] T. Dietz, C.T Whitley, Environmentalism, norms, and identity, Proc. Natl. Acad. Sci. 115 (2018) 12334–12336.
[76] J.M. Jachimowicz, O.P. Hauser, J.D. O'Brien, E. Sherman, A.D Galinsky, The critical role of second-order normative beliefs in predicting energy conservation, Nat. Hum Behav 2 (2018) 757–764.
[77] H Allcott, Social norms and energy conservation, J. Publ. Econ 95 (2011) 1082–1095.
[78] C-f Chen, K Knight, Energy at work: social psychological factors affecting energy conservation intentions within chinese electric power companies, Energy Res. Soc Sci 4 (2014) 23–31.
[79] A. Hansla, A. Gamble, A. Juliusson, T Gärling, The relationships between awareness of consequences, environmental concern, and value orientations, J. Environ Psychol 28 (2008) 1–9.
[80] F.G. Kaiser, H. Gutscher, The proposition of a general version of the theory of planned behavior: predicting ecological behavior1, J. Appl. Soc. Psychol 33 (2003) 586–603.
[81] G. Nair, L. Gustavsson, K Mahapatra, Factors influencing energy efficiency investments in existing swedish residential buildings, Energ Pol. 38 (2010) 2956–2963.
[82] Brohmann B., Hille S., Rennings K., Schleich J., Wüstenhagen R. What's Driving Sustainable Energy Consumption? A Survey of the Empirical Literature. 2009:1–24.
[83] E. Sardianou, Estimating energy conservation patterns of Greek households, Energ Pol. 35 (2007) 3778–3791.
[84] J. Heinonen, S. Junnila, Residential energy consumption patterns and the overall housing energy requirements of urban and rural households in finland, Energ Build. 76 (2014) 295–303.
[85] E. Hirst, R. Goeltz, J Carney, Residential energy use: analysis of disaggregate data, Energ Econ 4 (1982) 74–82.
[86] V. Brechling, S. Smith, Household energy efficiency in the uk, Fisc Stud 15 (1994) 44–56.
[87] S. Scott, Household energy efficiency in ireland: a replication study of ownership of energy saving items, Energ Econ 19 (1997) 187–208.
[88] C. Di Maria, S. Ferreira, E Lazarova, Shedding light on the light bulb puzzle: the role of attitudes and perceptions in the adoption of energy efficient light bulbs, Scott J. Polit. Econ 57 (2010) 48–67.
[89] D. Ürge-Vorsatz, J. Hauff, Drivers of market transformation: analysis of the hungarian lighting success story, Energ Policy 29 (2001) 801–810.
[90] B. Mills, J. Schleich, Household transitions to energy efficient lighting, Energ Econ. 46 (2014) 151–160.
[91] M.R. Ferguson, Energy-Saving housing improvements in canada (1979–82): a nested Logit analysis, Environ. Plann. A. 25 (1993) 609–625.
[92] S. Chen, H. Yoshino, N Li, Statistical analyses on summer energy consumption characteristics of residential buildings in some cities of China, Energ Build. 42 (2010) 136–146.
[93] L.F. Cabeza, D. Ürge-Vorsatz, D. Ürge, A. Palacios, C Barreneche, Household appliances penetration and ownership trends in residential buildings, Renewable Sustainable Energy Rev. 98 (2018) 1–8.
[94] G. Deng, P. Newton, Assessing the impact of solar pv on domestic electricity consumption: exploring the prospect of rebound effects, Energ Pol. 110 (2017) 313–324.
[95] S. Buryk, D. Mead, S. Mourato, J Torriti, Investigating preferences for dynamic electricity tariffs: the effect of environmental and system benefit disclosure, Energ Pol. 80 (2015) 190–195.
[96] E. Chappin, G. Dijkema, K. van Dam, Z Lukszo, Modeling strategic and operational decision-making - An agent-based model of electricity producers, Eur. Simulat. Model. Conf. 2007 (2007) 356–363.
[97] J.J. Jia, J.H. Xu, Y. Fan, Q Ji, Willingness to accept energy-saving measures and adoption barriers in the residential sector: an empirical analysis in Beijing, China. Renew. Susta. Energy Rev. 95 (2018) 56–73.
[98] R. Nakano, E. Zusman, S. Nugroho, R.L. Kaswanto, N. Arifin, A. Munandar, et al., Determinants of energy savings in Indonesia: the case of led lighting in bogor, Susta. Cities Soc. 42 (2018) 184–193.
[99] J. Rosenow, P. Guertler, S. Sorrell, N Eyre, The remaining potential for energy savings in uk households, Energy Pol. 121 (2018) 542–552.
[100] J. Thøgersen, Frugal or green? basic drivers of energy saving in european households, J. Clean Prod 197 (2018) 1521–1530.
[101] J. Thøgersen, Housing-related lifestyle and energy saving: a multi-level approach, Energ Policy 102 (2017) 73–87.
[102] Amouroux E., Huraux T., Sempé F., Sabouret N., Haradji Y. Simulating Human Activities to Investigate Household Energy Consumption. ICAART 20132013.
[103] I. Ajzen, The theory of planned behavior, Organ. Behav. Hum. Dec. 50 (1991) 179–211.
[104] Cialdini R.B., Goldstein N.J. Social influence: Compliance and conformity. Annual Review of Psychology2004. p. 591–621.
[105] S. Ahmad, F. Creutzig, Spatially contextualized analysis of energy use for commuting in India, Environ. Res. Lett. (2019) 14-4.
[106] G. Mattioli, Transport needs in a climate-constrained world. a novel framework to reconcile social and environmental sustainability in transport, Energy Res. Soc. Sci. 18 (2016) 118–128.
[107] J. Anable, C. Brand, M. Tran, N. Eyre, Modelling transport energy demand: a socio-technical approach, Energy Pol. 41 (2012) 125–138.