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Insights into End Users' Acceptance and Participation in Energy Flexibility Strategies

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Abstract: Ahead of the energy crisis, several countermeasures to reduce the energy demand require an active change in the end users' energy patterns. There are strategies known as demand response (DR) programs that have been tested in recent years, and they have showed us that users' behaviours can considerably reduce their effectiveness. This is due to a lack of sufficient knowledge, which leads to a lack of acceptance and participation. The key aim of this research is to detect which aspects influence acceptance of energy flexibility strategies the most. Through a series of tools, such as direct questionnaires, brief and user-friendly explanations, and analysis of variance, these aspects are studied by delving into specific topics such as smart home technologies, change in habits and patterns of energy use, and DR programs. In the literature, these topics have been studied separately, but they all contribute to the global acceptance: a comprehensive vision of the matter is the novelty of this work. The key findings are encouraging: 72% of the respondents demonstrated their willingness to enrol in a DR program. A reluctance to change habits was shown, in particular, among the age range 26–40, while women were more environmentally aware and more likely to participate in energy flexibility strategies. The modality of direct load control (which gives control to the utility company) is confirmed to be harder to be accepted (from 13 to 27% less acceptance depending on the category), with people who share a flat being the most likely to try it, and people who live with their parents being the less inclined ones. Acceptance increased when we provided plain language explanations, as seen in the case of smart home technologies: 97% of people who never tried them were declared to be willing to test smart technologies after a simple elucidation that was included in the questionnaire, showing that a right approach to the users led to a greater show of interest. This research highlights that the users' background and demographics characteristics (namely age, gender, educational level, home situation, home tenure, presence of children, and average income) should be taken into account when it comes to designing new energy flexibility strategies, since differences in the acceptance among groups have been found. The work also presents insights on the payback periods of legacy equipment in the EU energy context, demonstrating that a timely intervention can require half the time compared to that of the period prior to the crisis.

Keywords: demand response; demand side management; demand flexibility; IoT; users' acceptance

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1. Introduction

The Joint Research Centre of the European Commission has stated that "The roll-out of smart meters, the existence of smart grids, [is] an unobstructed market for Demand Response" [1]. This is a means to achieve the successful deployment of smart homes and the comprehensive home energy management system. The globalization of internet services and the spread of smart technologies over the last few decades are undeniable [2]. Particularly, lately, Internet of Things (IoT) applications for homes and appliances became a fashionable topic [3], as demonstrated by the impressive sales growth of devices such

as Amazon Alexa or Google Nest [4]. However, there is an important gap between the advancement of technology and its actual use among people in homes and workplaces, particularly for their use in providing non-entertainment services (energy, comfort, and wellbeing or e-health). In addition to that, the buildings we live in tend to have older technologies compared to those that have recently become available, which is something that is not true for other utilities we own. An easy to understand example lies in the diffusion of high-tech cars: In developed countries, most people own cars with double automatic control, heated seats, temperature and humidity control, etc. [5]. Conversely, around 40% of the European building's stock was built prior to the 1960s and never retrofitted [6]. It is hard to explain why people are willing to accept new technologies in other contexts, while showing such a reluctance to use them in their homes and workplaces. This is even harder to understand when we are considering that people spend up to 6% of their time in their cars and up to 90% of it indoors [7].

The EU is trying to solve this problem, based on the idea that improving the level of technologies in buildings can lead to an increase in people's well-being and to a smarter use of energy [8,9]. This is in line with the objectives on climate change [10] and reduction of greenhouse gas emissions [11], which in the European legislative framework, have been translated into directives focused on energy performance [12], energy efficiency [13], renewable energy [14], and energy innovations [15,16]. The targets of the reduction of GHG emissions could eventually be reached with aggressive changes in future technological adoption, although even this might not be enough [17]. The most recent step is the proposal of a common framework to evaluate the level of technology of a building: the Smart Readiness Indicator (SRI) [18], which will be used to enhance the 'smartness' of buildings. It is believed that such a novelty can give a encourage the uptake of smart homes, as well as encourage the general public to invest in smart technologies.

Another trigger, which may be more hidden but not less effective, is the rising cost of energy [1]. Consumers are starting to acknowledge that they have to change something in their habits and in their home systems to face the problem, and this can lead to an easier adoption of IoT technologies in their environment: they are starting to implicitly accept the concept of demand side management and flexibility [19].

Demand side management indicates that consumers pro-actively manage their demand to perform more efficient consumption [20]. In other words, this is the ability of end consumers to adapt their electricity consumption in response to the market and grid signals through the support of IoT technologies to achieve this aim. Demand management can concern the quantity of electricity consumed (peak shaving), the timing of its consumption (peak shifting), or both of them. The ensemble of such strategies is called demand response (DR) [21,22]. DR can be divided into several types [23,24], but one of the most agreed classifications consists of differentiating between price-based DR and incentive-based DR [25]. In incentive-based programs, customers receive incentives (or payments or discounted rates) to reduce their loads in a determined timeframe, which depending on the program, can last for minutes or for several hours. In some incentive-based programs, of which the most common one is direct load control (DLC), the control of the operation is left to the utility company, which can directly manage the home equipment through IoT technologies according to the needs of the grid. The subscribers receive notice beforehand (commonly, a day ahead) and can recover full control at their discretion if they feel uncomfortable [26].

Direct economic benefits are the main trigger that encourage the end user to enrol in DR programs. Although DR schemes usually require control and legacy equipment retrofitting, there is more potential to save money in comparison to that of the existing structure status of the building. The retrofitting itself is not enough to exploit the saving potential without the active participation of the users; according to Dall'O et al. [27], the potential to save energy by retrofitting in a business-as-usual scenario yields very small results (about 2.7%). In contrast, the active participation of the end user can provide savings of up to almost 25%. To achieve the highest tier of savings, as well as the highest tier of revenues for DR programs, more sophisticated equipment is required [28]. Different financial results can be

observed in different countries, but the overall energy savings remain the same. Zvaigznitis et al. [29] performed a cost–benefit analysis on energy efficiency interventions, comparing different business models in Eastern Europe. In recent years, independent research has taken place, yielding similar energy results [30,31] in various countries and economic areas.

While it has been described by Paetz et al. [32] that various components of the retrofitting procedure (such as smart meters) may have a relatively short payback period, this is not the case for the full deployment of the necessary equipment. This in turn means that in the baseline scenario comparison, if the investment is indeed higher than the expected earnings in the first year, the investment in energy retrofitting is relatively low. In addition, the actual cost has multiple dimensions that have to incorporate various aspects of daily life, such a restriction of the working performance, data loss, and equipment reconfiguration, or other inconveniences [33]. At the same time, technology is evolving, and better results can be obtained from a holistic approach to residential retrofit policies [34] that not only result in electricity savings.

Furthermore, Weber et al. [35] suggested that households with a low energy footprint are disproportionally affected by the cost of retrofitting, and that in cases of the tenants' presence, the tenants do not benefit from energy efficiency retrofits in financial terms. The majority of the relevant studies that concern retrofitting costs include, besides smart equipment, wall insulation or rendering. More specific research regarding the adoption of smart technologies in a household does indeed indicate that the initial costs that have to do with the procurement, installation, and maintenance of the necessary equipment are a major barrier [36–38].

Apart from economic aspects, there are also behavioural beliefs that can affect the users' acceptance, such as the opinions in the social environment, the willingness to differentiate oneself, the desire to impress the others, and so forth [39]. According to the Theory of Planned Behaviour [40], the behaviour is moved by the intention, which includes the attitude (the individual behavioural beliefs), the subjective norms (motivation to please one's significant others), and the perceived behavioural control (the difficulty to perform a specific behaviour). The energy-saving behaviour, in particular, has been correlated to some of Schwartz's personal value sets: altruistic (concern for others), egoistic (concern for personal resources), biospheric (concern for the environment), and hedonic (concern for comfort) ones [41,42].

This paper aims to evaluate the acceptance of end users through a questionnaire that was designed to achieve practical and comprehensible communication with the respondents and was based on the literature about the constructs that are relevant to the issue at hand. Concrete examples will be proposed that can easily match the interviewees' everyday life scenarios. The methods used for the questionnaire are explained in Section 2, while the outcomes are presented in Section 3. Section 4 provides discussions and practical considerations that revolve around the initial investment costs and realistic payback periods for participation in DR or energy efficiency programs. Section 5 presents the conclusions.

Literature Review about Acceptance of Demand Response Strategies

Incentives and economic benefits within the DR framework play a crucial role in the achievement of the consumers' acceptance, with the opportunity to save money being the major reason to change their consumption patterns. As seen in the previous section, there are other factors apart from achieving savings on bills that affect people's behaviour and acceptance. Detecting and analysing them has been the target of lots of work in the last few decades. Moreover, from the literature, it has emerged that DR strategies are very strictly related to several transversal topics and all of them influence the global acceptance of DR schemes.

The topic of the acceptance of DR solutions is analysed in a work by Tantau et al. [43]. They conducted a survey that was distributed in Serbia, Hungary, and Romania, collecting 195 forms. It appeared from their results that a very high number of interviewees (79%) declared they would participate in DR programs to reduce their energy bills. The respondents

also demonstrated a pro-environmental attitude, since 81% of them agreed to contribute to the reduction of CO_2 emissions and global warming. They also highlighted that maintaining the reliability of the system was found to be an incentive for the respondents, in particular, in areas where reliability represents a problem (e.g., frequent power outages). The questionnaire was not made available online, and from the results, one can deduce that the questions directly faced the topic of being in favour of the DR programs, failing to analyse the acceptance of several matters related to it: the need to use smart technologies, the need to change the patterns of consumption, the topic of remote control, and so forth.

Annala et al. [44] framed the problem in order to understand if motivations such as the reliability of the electric system and sustainability would be enough to obtain people's acceptance. They prepared two questionnaires: one of them was directed at a cohort of experts from the electricity markets and one of them was aimed at the general public. Both questionnaires were distributed in Finland, and the authors collected 32 forms on the expert side and 2103 forms on the general public side. Their main conclusion was that the non-monetary triggers cannot be considered as sufficient enablers, since the vast majority of the respondents declared that they would expect monetary compensation anyway. The results proposed within this research are mainly linked to the topic of the remote control of the appliances, while the other topics were left aside. However, the questionnaires were not made available online.

Yilmaz et al. [45] studied DR acceptance through a survey that was distributed in Switzerland. They obtained 622 responses among the customers of a Swiss public utility company. To evaluate the acceptance, they analysed the users' preferences about which appliances they would allow to be controlled remotely. They found that the acceptance for devices such as heat pumps and electric boilers is higher than that for appliances such as washing machines and dishwashers. Even more interestingly, they analysed the relationship between the demographic features and DR acceptance. For instance, for appliances such as dishwashers and washing machines, it was noticed that the presence of children and employment status served as significant predictors of acceptance. On these bases, they applied clustering techniques to identify four groups based on the level of acceptance and the socio-demographic data: conservative, reserved, agreeable, and flexible ones. Additionally, in this case, the interest of the authors was focalised on one single aspect of the DR scheme, namely the direct load control of specific appliances.

Regarding the users' preferences, Schwarzer et al. [46] studied the acceptance of the DR system by analysing the temporal flexibility of 119 users who were invited to fill out an online questionnaire. Their main finding was that acceptance does not increase with more configuration possibilities or more timeslots. Dütschke et al. [47] conducted a survey to analyse the relationship between DR acceptance and pricing programs. They collected 160 questionnaires from which they demonstrated that fixed timetables are preferred over dynamic pricing. In a work of Thorsnes et al. [48], 400 households were recruited to participate in an experiment to evaluate the acceptance of a specific DR program, namely time-of-use pricing. The success of the time-of-use programs lies in the capability of the users to change their consumption. To achieve that, the experiment consisted also of sharing tips with the users to increase their level of knowledge about energy conservation. The results indicated very modest responses from the participants. As an interesting finding, it was noticed that there was more acceptance and a better ability to change their load during summer than that was during winter. Another experiment on pricing was conducted in California through a Statewide Pricing Pilot [49] scheme that involved approximately 2500 customers and tested several electricity rates. The aim of the work was to evaluate acceptance through the smart technologies and legacy equipment that enable the automated responses to the needs of the grid. Results were very promising: automated responses were preferred to the manual control of appliances. In particular, it was noticed that the reduction of the consumption by users with enabling technologies (which were installed free of charge) was larger than the one obtained by the other participants. In a pilot conducted in Ontario [50], the responses of 500 customers with respect to DR pricing rates

were assessed. The results are encouraging, and the effectivity of the program depended largely on the individual usage patterns. Thus, the main finding was that users would rather change the usage patterns on their own, since the idea of giving control to the electricity supplier raised many concerns.

On the use of smart home technology, McKenna et al. [51] faced the problem of the privacy concerns raised by the users. They underlined that DR would be impossible to put into practice without some key enabling technology, such as smart meters. However, the consumers' privacy concerns can lead to a delay in their development and diffusion. The work suggests a revision of the electricity supply industry's requirements for sensitive data in the smart home context. Concerns regarding data privacy are also analysed in the work of Paetz et al. [32], which aimed to analyse the acceptance of smart home technologies. Twenty-nine users took part in their experiment, which consisted of a group discussion, which was an informative conversation, and a pre–post-questionnaire that evaluated the willingness to use smart technologies and the pro-environmental attitude. Interesting statements that revealed the users' preferences were collected, giving a precious insight into the main reasons for the rejection or acceptance of smart home technologies. Among them were the already mentioned privacy concerns and the difficult of changing some activities. From the pre–post-questionnaire, instead, the main finding was that users have a wrong perception of the relationship between costs and revenues, leading to an overestimation of the payback periods. The innovation acceptance in the building sector is further studied by Sepasgozar and Davis [52], who tested the customers' decision-making practices. Through semi-structured interviews, they collected data regarding the technology adoption, the consumer expectations, and to match the strategies to them. This topic will be addressed in Section 4.2.

Regarding the patterns of consumption, the studies examined suggest that residential consumers are not able to significantly change their patterns of use depending on the price of the electricity or the needs of the grid. During the early stage of the research on the topic, the main issue seemed to be related to exaggerated saving expectations, as demonstrated by the Electricity Smart Metering Customer Behaviour Trials [53] performed in Ireland by the Commission for Energy Regulation, in which more than 5000 users participated. Electricity usage had traditionally been considered as a passive routine, hence users preferred to return to their normal patterns when their behavioural changes were not mirrored in the bill reduction. More recently, the perspective changed when White and Sintov [54] demonstrated that the real factor that influences the consumers' acceptance is not the bill saving, but the perceived bill saving. Furthermore, the perception that users have of the saving has a weak association with the actual one. According to this work, the first factor that feeds this bias is the lack of understanding of the electricity consumption related to specific actions or appliances. Hence, giving the users more concrete information could narrow the gap between the perceived savings and the actual ones, increasing the acceptance of the DR strategies.

Despite the enablers and the willingness and the positive attitudes demonstrated by the participants of the surveys considered, studies based on real DR programs showed that the goal of the users' acceptance is far from being achieved. Tomat et al. [26] demonstrated that acceptance is a factor far from being related to the mere enrolment in a DR program. A data-driven analysis showed that many users who participate in DR programs fail to accept both the change in patterns of consumption and the remote control over their HVAC systems. That is why a global understanding of the different facets of the matter is essential to design DR strategies correctly. In fact, for the end users, the acceptance is not only related to the willingness to enrol in a DR program, but it also involves and includes: a change in their patterns of consumption, the willingness to give control over their appliances, the use of smart technologies in their daily life. The gap that we found in the existing literature consists of the lack of a holistic view of the acceptance: the mentioned works give great contributions on a single aspect of the paradigm, but they fail to analyse the global acceptance of the energy flexibility strategies.

Our mission with this work is to fill this gap by taking into account several facets that compose the topic. The analysis of the literature has been a starting point for our work since it has been used to identify the main barriers to participation in DR strategies:

- Privacy concerns are the most frequently raised issues: people do not feel safe about the security of the data collected by smart meters [52].
- The initial investment to increase the 'smartness' of a home: it appeared that some users overestimate the payback time for the acquisition of smart technologies (as an example, the real payback time for smart meters is one year [32]).
- Loss of control over the appliances: some users do not want to delegate the decisions about their electricity usage to the power utility company [50].
- Lack of knowledge: most consumers are not fully aware of their consumption patterns, nor of how the electricity markets work [55].

Other concerns detected are more related to the changes in the activities, in particular, in the case of remote control:

- Incompatibility with the lifestyles, in particular, for the users who spend most of their day at home (retired people, people with small children, and remote workers) [50].
- Noise during the night, which can bother the other household members or the neighbours [32].
- Difficulty in changing meal times (which is why, in most studies, consumption related to cooking is typically considered to be unchangeable) [56].
- Adequacy of water/room temperatures, which can drop below the established limits [44].
- Possibility of malfunctioning/functioning in a non-agreed way [44].

2. Materials and Methods

Rationale of the Questionnaire

The multi-part survey was developed to investigate the acceptability of energy flexibility strategies in a residential context, which intended to record the requested changes by consumers in their energy demand patterns. The effectiveness of programs based on the flexibility of the end users' demand relies on people's acceptance, which is often compromised by the users' preferences. Through this questionnaire, we aim to evaluate how these strategies are perceived by the public [57].

On the other hand, the occupants' awareness and energy literacy are the pillars of demand side management. According to several studies [58,59], users tend to adopt a pro-environmental attitude if they are conscious of the consequences of overusing energy (higher costs, increase in CO_2 emissions, instability of the grid, and so forth). In fact, psychological and behavioural factors play a key role in people's decisions: giving control and responsibility to consumers can encourage their engagement, and ultimately, an improvement to society's energy consumption. Hence, the questionnaire also intended to increase people's awareness of their energy use to enhance their literacy about the consumption of appliances and implicitly suggest the optimization of their consumption schedules.

To make sure that the analysis was conducted in a coherent way regarding the way in which the technology is advancing, the questionnaire was built from an IoT perspective and meant to analyse the disposition towards smart home technologies. This work supports the spread of smart home technology as an indispensable ally for a smoother transition toward more efficient management of the energy demand.

Scope

The questionnaire proposed in this work has a two-fold aim of (1) analysing the users' attitude towards the DR programs, which also implies the use of IoT technologies for their homes and the change in their patterns of consumption and (2) raising the awareness and the literacy of consumers, with the belief that the users' commitment is the key to the flexible strategies' success.

The first aim entails several sub-objectives, which are listed in Table 1. In order to map the questions in the next sub-section, each sub-objective is assigned a colour.

Table 1. List of sub-objectives of the questionnaire and colour legend. A colour is assigned to each sub-objective in order to refer to them in the other tables of the section.

List of Sub-Objectives	
Evaluation of the consumers' awareness of the topic	
Evaluation of the consumers' attitude toward changing their schedules	
Evaluation of the consumers' attitude toward the use of IoT technologies in their homes	
Evaluation of the consumers' attitude towards DR programs	
Evaluation of the appropriate incentives to subscribe to a DR program	

Regarding the second aim, several text boxes were inserted into the questionnaire with information to help them to complete the survey. These brief paragraphs are written using user-friendly language, and the concepts are explained in a simple and clear way. Several aspects are covered, namely what smart technologies are and what typologies are used in smart homes; how the peak consumption is obtained through the contemporary use of many appliances and what happens if it uses more than the contracted power; what are the DR programs and what the smart charging of electric vehicles (EV) qualifies as. In addition, the questionnaire contains two explanative sub-sections: 'what is the survey?' and 'motivation'.

Structure

The questionnaire is structured as follows:

- A brief explanatory introduction.
- Motivation.
- Demographics.
- Level of knowledge.
- Appliances.
- Air conditioning.
- Electric vehicles.

The demographics section is composed of six items and has the aim of analysing the profile of the respondents, since in the literature, it was seen that demographic data can influence the willingness to accept DR strategies. The questions in this section were selected after a thorough study of the literature. In particular, this section collects data about: age, gender, level of study, residential situation (e.g., shared flat, parents' home, and so forth), presence of children, and housing tenure. More information is given in Table 2.

The level of knowledge section investigates the awareness of the electricity tariff, the use of smart technologies for appliances, conscious consumption, and knowledge of the DR programs' existence. The section also contains an explanatory part where the DR programs are briefly described in order to assist the respondent in understanding the questions. Some items are inspired by the study of Dewaters et al. 39 on energy literacy, among others. The questions are presented in Table 3.

Table 2. Questionnaire—demographics and background section.

Demographics and Background Information	Comments/Justification
Age	Age groups were classified to correspond to: early young adults (18–25), late young adults (26–40), middle adults (41–60), and old adults (>60 years old). Age is usually correlated with a resistance to change.
Gender	Gender was included as a variable to see if there are differences in the perceptions of smart home technology and flexibility strategies between men and women.
Education level	There is an assumption that people with more technical education, thus having been exposed to technology more, are more prone to accepting new technologies in their homes.
Residential situation	Participants were asked to declare whether they live alone, with family, a partner, or in co-housing, as background information.
Presence of small children	Families with small children are usually correlated with resistance to flexibility.
Housing tenure	Certain aspects, such as the cost of smart systems installation or the property value upgrade that comes with it, might be perceived differently by homeowners and private renters.
Income	It was found in the literature that the willingness to accept economic incentives is sometimes related to the financial situation of the participants.

Table 3. Questionnaire—level of knowledge section. For the colour legend and the corresponding sub-objectives, please refer to Table 1.

Level of Knowledge	Aim (from Table 1)	Comments/Justification
Do you know which electricity tariff is contracted for your home?		If the user does not know which tariffs are applied to their consumption, it can be difficult for them to empathise with the rest of the questions
Do you know what smart technologies are?		The question is followed by an explicative text about smart home technologies, smart meters, smart sockets, and smart appliances
Do you use any smart technology for your appliances		The question also evaluates the willingness to use them
Please rate the following sentences about smart technologies from strongly disagree to strongly agree		General opinion about smart home technologies. In the questions, some main enablers and barriers that have been found in the literature are mentioned (e.g., concerns about the use of personal data, willingness to impress the others, et.) [39,40]
Please rate the following sentences about changing habits from strongly disagree to strongly agree		General opinion about changing the pattern of use. Some factors that can affect the willingness to change schedule, according to what is found in the literature [44], are considered in the questions. For example, it has been found that people who experiment with recurrent power outages are more willing to modify their patterns to solve the problem. Items about the effects of our habits on climate change are also proposed [60].
Do you know what a demand response program is?		The question is followed by an explicative text about DR programs, and a distinction between price-based and incentive-based programs is proposed [21] in user-friendly language.
Please, rate the following sentences about demand response from strongly disagree to strongly agree		General opinion about DR programs. After reading the explicative text, this question collects some first impressions about the topic. Some references to the theory of planned behaviour [40] are also included.

The appliances section includes questions that are relevant for understating the use of appliances by the participants. As presenting them in terms of kWh may be not representative for the layperson, we have included an example of the consumption rate estimated to prepare breakfast, considering the contemporary use of several appliances at the same time. This easy-to-understand example is used to give to the respondents a conceptual landmark, since it is shown in the literature that the perception that the users have of their consumption does not correspond to reality 54. Then, the questions aim to investigate if the respondents would be willing to change their schedule and what incentives they would expect to receive. It also analyses the attitude toward the possibility of ceding control over the appliances and what incentives the users are expecting in return. The rationale of the questions is presented in Table 4.

Table 4. Questionnaire—appliances section. For the colour legend and the corresponding sub-objectives, please refer to Table 1. * The appliances listed in the table refer to: a washing machine, a tumble dryer, a dishwasher, a vacuum cleaner robot, and a water heater. The respondent can also insert another appliance that is not already present in the list.

Appliances	Aim	Comments/Justification
Would you be willing to change some of your habits?		The respondent can check as many items as they want. The answers proposed are cooking time, doing the laundry, ironing, and using the dishwasher [44], but the respondent can give an open answer as well.
If you did not check some of the activities, can you very briefly explain why?		The suggested answers are taken from the literature [39], for instance, considering that it requires too much effort. The respondent can give an open answer as well.
Would you change your pattern of use?		The respondent has to indicate an answer (yes/no) for each one of the appliances *.
Would you give control to the utility company?		The respondent has to indicate an answer (yes/no) for each one of the following appliances *.
For what incentive?		The respondent has to indicate an answer (EUR 50, EUR 100, EUR 250) for each one of the following appliances *.
If you did not check some of the appliances, can you very briefly explain why?		The suggested answers are taken from the literature, namely too much noise during the night, concerns about malfunctioning/functioning in a non-agreed way, and security concerns [32,44]. The respondent can give an open answer as well.
Would you prefer to be responsible for changing your consumption, or would it be easier for you to leave the management of your appliances to the utility company?		It is implicitly suggested that it is hard for users to change their patterns on their own, as indicated in the literature [44,54]

The air conditioning section is dedicated only to the interviewees whose home is equipped with an electrical cooling and/or heating system. A scenario based on a plausible pattern of use of air conditioning on a summer day is presented with the relative cost consumption. The questions evaluate the acceptance of the eventual rise in temperature, the willingness to cede control to the utility company over the HVAC system, the acceptance in the case of precooling, and the incentives expected. The questions are explained in Table 5.

Table 5. Questionnaire—air Conditioning section. Beforehand, the respondent was asked whether they have electrical heating and/or heating system in their home. For the colour legend and the corresponding sub-objectives, please refer to Table 1.

Air Conditioning	Aim	Comments/Justification
Would you be willing to raise the setpoint temperature by two degrees, knowing that it will lead to a saving of 2/3 of the cost that day?		To answer this question, the respondent is asked to picture a hypothetical scenario of a summer day. The consumption refers to a three-hour usage period using air conditioning, with patterns inspired by real cases analysed in a previous work [26].
Would you be willing to give control of the setpoint temperature to the electric company in exchange for incentives?		It is specified to the respondent that they would be notified in advance and they would be able to regain control if they felt uncomfortable. It is also explained through the questionnaire that the control is given away in specific timeframes, i.e., that is a temporary situation.
Would you be more willing to accept if your home would be precooled for free in advance?		Precooling is a common practice in DLC programs in order to maintain the occupants' thermal comfort [21,26].
How much would you expect to receive as an incentive to give control to the utility company?		Respondents can also give an open answer if no previous option is considered to be adequate.

The EV section is dedicated only to the respondents who own an electric car scooter or bicycle. After asking how charging is usually managed, a brief explanation of how the smart charging works is presented. The last questions aim to evaluate the acceptance of this way of charging and that incentives that would be expected. The questions are listed in Table 6.

Table 6. Questionnaire—electric vehicles section. Beforehand, the respondent was asked whether or not they own any electrical heating and/or heating system in their home. For the colour legend and the corresponding sub-objectives, please refer to Table 1.

Electric Vehicles	Aim	Comments/Justification
How do you manage the charging?		This question is meant to understand whether the respondent is already used to letting the vehicle plug in at night or if another method is preferred.
Did you know this way of charging		The question refers to smart charging, which is explained directly above in the questionnaire.
Would you be willing to use it?		To obtain an informed response, it is explained to the respondent that in case of a personal emergency, the vehicle could not be fully charged/available.
How much would you expect to receive as an incentive per year?		Open answer.

Distribution

The questionnaire was achieved through an internal platform of the University of Murcia called Encuestas (Encuestas is a tool that allows the staff of the university community to design surveys, publish them, and exploit the results obtained, with the advantage of being integrated with the corporate database of the University of Murcia). The choice to not involve third parties in the collection (using other platforms) was a way to assure both the anonymization and protection of the data collected.

The questionnaire was distributed as an online form through email invitations. The intention was to reach people from different geographical contexts and with different backgrounds, so that the feedback could be a good representation of the general public.

Respondents had to download and accept a consent agreement before starting the survey according to GDPR European regulation.

It is important to specify that the participation to the survey was totally voluntary in order to assure the validity of the forms received.

Fifty filled-in questionnaires were collected during the distribution campaign, which took place in the period 1–9 August 2022.

MANOVA Test

Multivariate analysis of variance (MANOVA) is a test that analyses the relationship between several response variables and a common set of predictors at the same time, and it has been widely used since the 1980s [61]. It is an extension of the univariate analysis of variance (ANOVA) [62]. The technique determines the influence of independent categorical variables on multiple dependent variables, establishing whether or not the categories differ from each other significantly in some characteristics. It is an extremely versatile method for data analysis that can be applied to every field, among which are the energy in buildings [63] and energy literacy fields [60]. Among several statistical test that are available, this work will refer to Pillai's Trace, which is considered one of the most robust typologies, especially for the cases of departures from the MANOVA assumptions [64].

The analysis was performed in Python using the statsmodels module. When Pillai's trace showed a statistically significant association (p-value < 0.05), a post hoc test was performed through a Tukey HSD test (Honest Significant Difference) to understand which category of the independent variable is the one that differs. If the Tukey test rejects the null hypothesis, it means that the absolute value of the test statistic is greater than the critical value, hence it confirms that the difference is significant. If it is not specified otherwise, the critical value used in this work for the Tukey test is 0.025. Once we identified the one dependent variable that was being influenced, an ANOVA test was used to fit a linear model and to obtain the corresponding p-value. The smaller the p-value is, the more the variable is influenced by the independent categorical variable. The differences between the categories were be made more understandable through specific plots.

3. Results

Demographics and Background

The first output presented concerns the demographics and the educational background to try to define the profiles of the respondents. The analysis in this part of the questionnaire allowed us to draw a picture of the participants. They were from Spain, Italy, Greece, the United Kingdom, the United States, Switzerland, Austria, Denmark, and Ireland. Among the 50 filled-in questionnaires that we received, 7 (14%) respondents were early young adults (age range 18–25), 38 (76%) respondents were late young adults (age range 26–40), 4 (8%) respondents were old adults (age range 41–60), and only 1 (2%) respondent was over 60 years old. Sixty-four percent of the respondents identify themselves with the male gender, and the remaining thirty-six percent of them with the female gender. The vast majority (76%) of the respondents were postgraduates; 18% of them were graduates and 6% of them received a professional education.

Considering the home situation, 28% of the respondents lived with their parents, 26% of the respondents lived with their partner, 24% of the respondents lived alone, and 22% of the respondents lived with flatmates in a shared apartment. Among them, the vast majority (88%) did not live with small children. Half of them (50%) owned their own home, while the other half lived in rental accommodation.

Finally, here is a small insight into incomes. To evaluate the incomes, the average monthly salaries of some European countries were indicated as additional information to help answer this question. Hence, each respondent could easily compare their incomes with the average one in their country, sharing if their salary was higher or lower than the indicated amount. In this way, the interviewees were not asked to share their exact earnings, which can be uncomfortable or can raise privacy concerns. Fifty-two percent of

them answered that their income was slightly above the average of their countries, 32% of them answered that it was slightly below it, 14% of them answered that it was much below the average, and just one participant estimated to have an income that was much above the average in their country.

These data represent the independent categorical variables for the MANOVA test.

Level of Knowledge about the Topic

To complete the profile of the respondents, it was important to analyse their background in terms of knowledge about the topics proposed in this section, i.e., use of smart technologies, willingness to change habits, and understanding of the demand response programs.

Forty-four percent of respondents declared that they were not sure about which electricity tariff was contracted in their homes.

About smart technologies, 68% of interviewees knew what they were, and 32% of them even used smart technologies in their homes (in particular, smart sockets). Twenty-four percent of them had heard about them, but they did not go deeper into the topic, while 8% of them declared they had never heard about them. After reading the information available in the questionnaire, 97% of the people who did not already own any smart technology declared they would be interested in trying to. Finally, 36% of the respondents affirmed that they knew what demand response is, while 40% of them did not; the remaining 24% of them had heard about the topic without explaining further.

For brevity, the questions for which the five-point Likert scale was used are shown in form of tables that can be found in the Appendix A (Tables A1–A3). One should have in mind that before the following items were proposed in the questionnaire, the interviewees could provide related information in user-friendly language.

From the MANOVA test (Figures 1 and 2), it appears that gender has a significant influence on the use of smart technologies ($p = 0.008817$), on the individual effort to mitigate climate change ($p = 0.029477$), on the willingness to save energy and to encourage their cohabitants to do the same ($p = 0.013645$), and on the willingness to participate in a DR program ($p = 0.003106$).

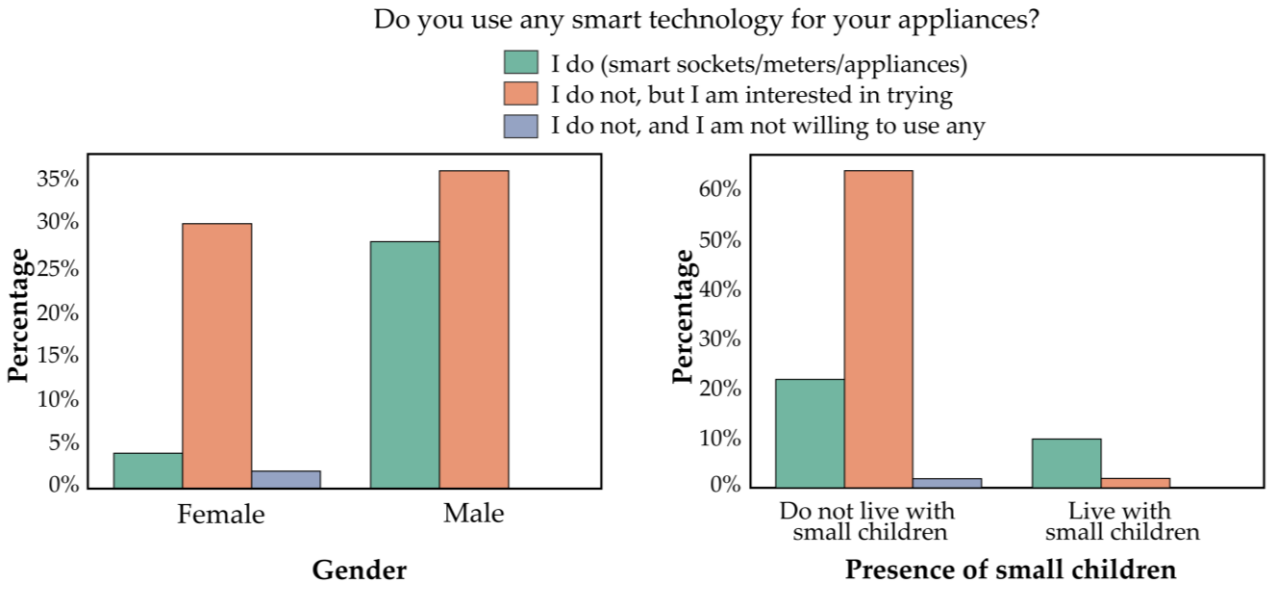


Figure 1. Countplots of the significant differences in demographics on the use of smart technologies. The *y*-axis expresses the percentage of respondents, while on the *x*-axis, the categories of the independent variables are shown.

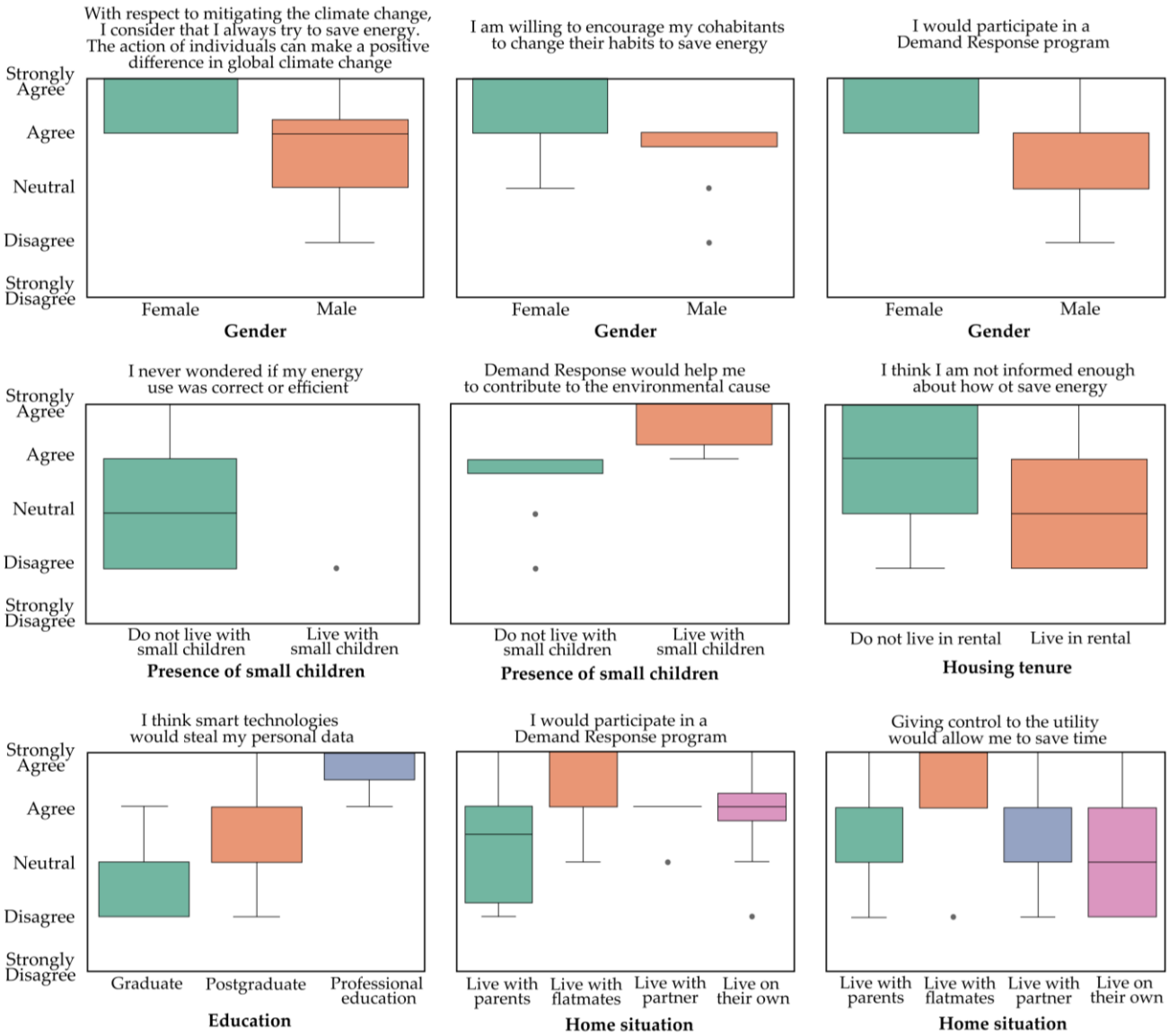


Figure 2. Boxplots of the significant differences in terms of the demographics on the level of knowledge. The *y*-axis represents the 5-point Likert scale, while on the *x*-axis, the categories of the independent variables are shown.

Education has a significant influence on the belief that smart technologies would steal their personal data ($p = 0.017076$): the Tukey test showed a significant difference between the graduates and the people that received a professional education. Living in rental accommodation has a significant influence on considering oneself not informed enough about how to save energy ($p = 0.0247$). The presence of children has a significant influence on the use of smart technologies ($p = 0.004652$), on wondering if their personal energy use is correct or efficient ($p = 0.011153$), on the previous knowledge of the DR programs ($p = 0.009331$), and on the belief that DR programs would help them to contribute to the environmental cause ($p = 0.013896$).

The home situation has a significant influence on the belief that giving control to the utility company would allow them to save time ($p = 0.027418$); the Tukey test showed a significant difference between people who live on their own and people who share a flat. The home situation has also a significant influence on the willingness to participate in a DR program ($p = 0.035323$). Using a critical value of 0.025, the Tukey test did not identify which categories showed significant differences; using a critical value of 0.075, the test showed a

difference between people that live with their parents and both people that live with their partners and people that share a flat. This difference in the critical value simply means that the influence is not as strong as it is in the other case, as is also confirmed by the *p*-value; considering that the limit of significance is $p = 0.05$, 0.035 is a rather high value. The other independent variables, e.g., age and income, do not have a significant influence on the level of knowledge.

To graphically visualise the differences highlighted by the MANOVA test, in Figures 1 and 2, the countplots (in the case of percentage scale, as indicated on the *y*-axis) and the boxplots (in the case of Likert scale, as indicated on the *y*-axis) are depicted with the answers in the corresponding categories. The plot title corresponds to the question proposed to the respondents, while the plot legend (in the counterplots) represents the options among which the respondent had to choose from. On the *x*-axis, the demographic categories are indicated, which represent the independent variables of the test; for instance, for the category 'house tenure', the answers given by people who live in rental accommodation and the ones given by people who do not live in rental accommodation are indicated separately on the *x*-axis.

Appliances

In the first part of this section, the respondents were asked if there were some habits that they would not change in order to explore the barriers to the flexibility strategies. Half of the participants would not change their cooking time, 30% of them would not change their habit of doing the laundry, 10% of them would not change their habit of using the dishwasher, 6% of them would not change their ironing time, and 4% of them would not change their computer use. Note that 26% of the respondents selected more than one habit. About the barriers that prevent them from changing habits, 42% of the respondents answered that the main reason was their busy schedule, which would make it difficult to change the schedules. Eight percent of them indicated that changing their habits would require too much effort. Another 8% of them considered they need to repeat very frequently habits such as doing the laundry and using the dishwasher. The rest of the interviewees indicated reasons such as work at home, time constraints, personal comfort, and the need to cook many meals just before eating. Finally, one respondent considered that they would not change their habits since they have already organised them to save energy.

The MANOVA test (Figure 3) gave more information about these outcomes. Age has a significant influence on the possibility to change the cooking time (*p*-value = 0.006398) and on considering the busy schedule as the main barrier (*p*-value = 0.007149). The difference was detected between the age ranges of 18–25 and 26–40. The home situation has a significant influence on the possibility to change the ironing time (*p*-value = 0.014782). In particular, people that live on their own gave different answers to those of the people that live with their parents, their partners, or their flatmates. The presence of small children has a significant influence on the possibility to change the laundry time (*p*-value= 0.037233) and on indicating the need to do the laundry frequently as the main barrier (*p*-value = 0.014192). Finally, the average income has a significant influence on the possibility of changing (1) the cooking time ($p = 0.021284$, between the categories 'much below average' and 'slightly above average', Tukey's critical value = 0.05), (2) the dishwasher time ($p = 0.015294$, between the category 'much above average' and all of the others), and (3) the ironing time ($p = 0.000105$, between the category 'much above average' and all of the others), and on considering the effort required for these changes as the main barrier ($p = 0.004689$, between the category 'much above average' and all of the others). The plot title indicates the independent variable considered and the main topic of the question proposed to the respondents. The plot legend represents the demographics features. The *y*-axis shows the percentage of respondents. To answer the questions in this section, the respondents could mark several answers on a check list. Hence, the answers are divided into two poles, which are indicated on the *x*-axis. For instance, in the plot 'influence of the age range on the willingness to shift the cooking habit', on the left, the respondents who explicitly indicated the 'cooking time' as a

habit that they would not be willing to change are indicated, while on the right, the other respondents who left the corresponding box unchecked are showed.

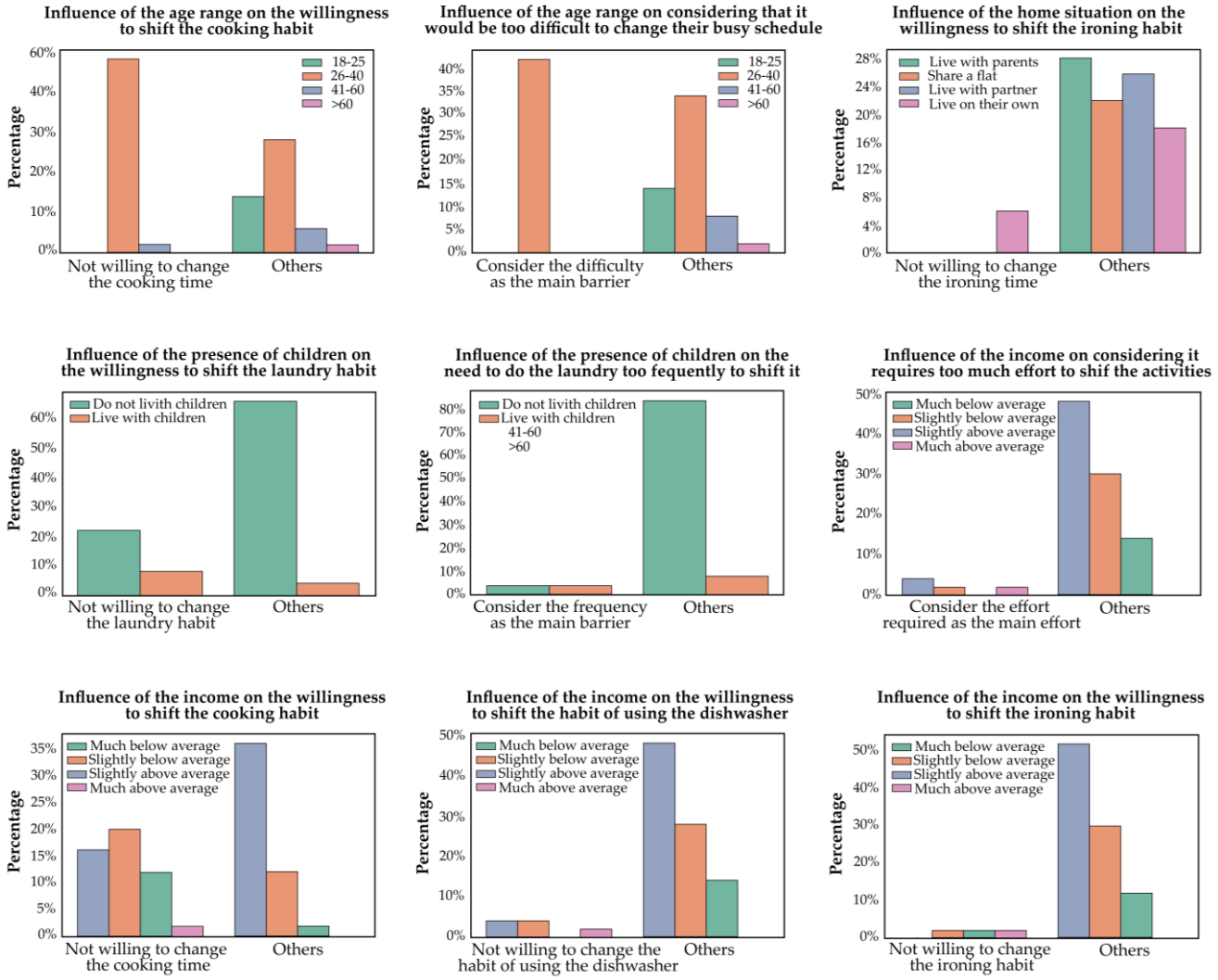


Figure 3. Countplots of the significant differences in demographics on willingness to change habits. The *y*-axis expresses the percentage of respondents, while the categories of the independent variables are shown in the legends. Since the items required a binary answer, the two poles are presented on the *x*-axis.

After this first part, it was explained that through smart technologies, one can change their consumption even if they are not at home or sleeping. The objective was to show that most of the barriers indicated (a lack of time and difficulty in organising the day) can be overcome by controlling their appliances remotely or by letting the utility company manage them to obtain optimised results. Some main appliances that may form part of the respondents' daily life have been proposed. For each one, it was asked if they be willing to change their usage schedule and/or give control to the utility company, and how much they would expect to receive as an incentive. For brevity, the results are shown in the Appendix A (Table A4). For the expected incentive, the only independent variable that has significant influence is housing tenure, with a *p*-value that varies between 0.023461 and 0.029747.

When they were asked about the barriers to the proposed appliances or to others, 16 respondents were worried about them malfunctioning or functioning in a non-agreed way, 11 respondents thought that the appliances would make too much noise at night,

and 8 respondents had security concerns. Ten people preferred to give an open answer. Here are reported some examples: "using sunlight to dry my clothes means I can't use the washing machine during the night", "With a good app/smart-home setting I could manage them well enough", "I will not voluntarily relinquish one single inch of control to any utility company", "I might need to take a shower and cold water is a no-go", and "Probably companies would try to get money out of being able to use the appliance in convenient times".

Finally, they were asked to express a preference between being responsible for changing the consumption or leaving the management of it to the utility company. Fifty percent of the respondents would delegate it, and 50% of them would manage it themselves.

Air Conditioning and Electric Vehicles

The section on air conditioning as well as the section on electric vehicles were meant to be filled in only by people who actually have electrical HVAC systems and/or electric vehicles. From the full cohort, thirty-three people completed the air conditioning section, while only two people completed the electric vehicle section, which is consistent with the current percentage of electric vehicles within Europe [65].

The objective of the air conditioning section is to understand the rate of acceptance of the demand response programs that work using the HVAC systems. In the summer scenario, which was the one proposed to the respondents, a demand response event would consist of raising the setpoint temperature for a certain amount of time in correspondence with the peak of consumption. In the DR framework, the increase in temperature is managed by the utility company and, in most cases, is preceded by a precooling phase. The aim of the section is to evaluate these elements separately to understand which part of the DR strategy is harder to accept by the general public and if the precooling phase and the economic incentives can mitigate their opinion.

Using a practical example of cost reduction obtainable by raising the setpoint temperature by two degrees, 70% of them declared they certainly would change the temperature, while 12% of them stated that they would not, since they prioritised their comfort, hence a cooler temperature in summer. The remaining 18% of them were not sure.

When they were asked if they would cede the control of the thermostat to the electric company to perform the change in the setpoint temperature, with notice on day prior and in exchange for incentives, 55% of them answered they would. Twenty-seven percent of the respondents remained neutral, explaining they it would depend on the incentives, and 18% of them would not give control to the utility company no matter the incentives.

Regarding the precooling phase, the users were asked if they would be more willing to accept the increase in temperature if their home would be precooled for free in advance. Of them, 49% answered that this factor would convince them, 24% that it would still depend on the incentives, and 6% confirmed that they do not feel comfortable with ceding the control under any condition. Interestingly, 21% of the respondents do not think that the precooling phase would be necessary, which is in line with the evidence from a real dataset analysis, in which 3% of the participants manually interrupted the precooling phase, and around 9% of participants chose a higher setpoint temperature to restore their comfort during the hours that followed the DRE with precooling 26.

Finally, here are the insight into the enablers: In this regard, 25% of them declared that they would give control to the utility company because of a pro-environmental attitude, hence the monetary compensation would not be of their concern. Eighteen percent of them would accept, as an incentive, enabling technologies installed free of charge. Of them, 51% of them would accept monetary compensation of EUR 50/year (15% of the interviewees), EUR 100 /year (15%), and EUR 250 /year (21%). The remaining 6% of them affirmed that none of the options would convince them.

The MANOVA test (Figure 4) showed that age has a significant influence on the kind of incentive that would convince them to cede the control to the utility company (p = 0.007296); the Tukey test detected a difference between people with an age range of 41–60 and younger people (both of the ranges 18–25 and 26–40). Education has a

significant influence on the acceptance of raising the setpoint temperature that would lead to a cost reduction (p = 0.000332); the Tukey test showed a significant difference between postgraduates and people that received a professional education. Level of knowledge and personal beliefs have no significant influence on the acceptance of the DR programs that work on HVAC systems.

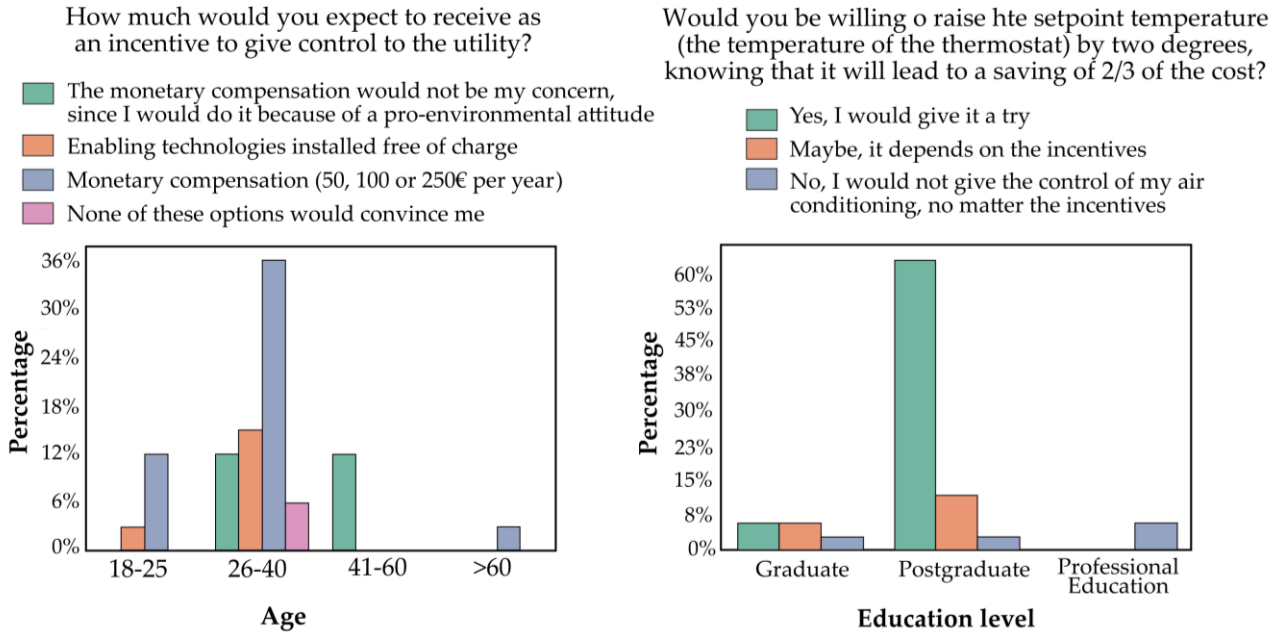


Figure 4. Countplots of the significant differences in the demographics on the HVAC items in the questionnaire. The y-axis expresses the percentage of respondents, while on the x-axis, the categories of the independent variables are shown.

The objective of the electric vehicles section was to understand if the respondents would change their actual way of charging in favour of smart charging. In the informative part, we also explained the risks related to smart charging, for example, in the remote case of a personal emergency in the middle of the night, the vehicle might not be fully charged. Both of the respondents declared to be willing to try smart charging for their electric vehicles.

4. Discussion

4.1. Analysis of the Survey Results

The objective of this section was to organise the results since, considering the large number of data presented in the Section 3, it can be helpful to decipher into the meaning of these data.

First of all, it is important to have in mind the results of the demographics part when one is interpreting the results, in particular, when significance tests are involved. The objective was to have a variegated ensemble of respondents that could represent the general public. In some variables (e.g., home situation and home tenure), all the categories considered are well represented, since the sample sizes are similar and comparable. In other variables, the sample sizes of the category are quite different (e.g., education level and presence of children). There are two potential issues to be aware of when one is performing a significance test such as ANOVA with unequal sample sizes: reduced statistical power and reduced robustness to unequal variance. To propose an example from the air conditioning section, the education level results to have a significant influence on the willingness to raise the setpoint temperature during determined timeframes to achieve a cost reduction. The p-value is very low, indicating a very strong influence. This result is considerably interesting despite the unequal sample size. It is even more interesting considering that,

for instance, a variable more related to the costs, such as the average income, was not considered to be influencing. However, one should be aware that the strength of the found influence could be either reduced or confirmed when one is analysing bigger or more equal samples.

Regarding smart technologies, after reading the related information given, there was a general agreement to consider them a means to save money, time, to have more commodities, and being easy to use. Opinions were more diversified considering the worries about the personal data and the opinions of the significant others: in these cases, the overall result indicates a tendency to remain neutral (neither agreement nor disagreement prevailed).

About the energy consciousness related to the habits, the respondents seemed to consider themselves responsible consumers that are committed to energy saving (76% of them agreed or strongly agreed that they always try to save energy to mitigate climate change, and 82% of them are willing to encourage their social environment to save energy). This tendency is more evident in women: for instance, 100% of the female respondents agreed or strongly agreed that they always try to save energy to mitigate climate change versus 65% of the male respondents (Figure 2). There is a prevalence of agreement with the idea that other people are not informed enough (72%), but when it comes to considering oneself as informed on how to save energy, the numbers of people who agreed and of people who disagreed are equal. About this point, people who live in rental accommodation generally consider themselves to be less informed, as shown in the boxplots in Figure 2.

From the general section about DR programs, the feedback is encouraging: 72% of them agreed or strongly agreed that would enrol in a DR program, and 76% of them agreed that it would be a good way to contribute to the environmental cause. This is in line with the findings of Tantau et al. [43]: among their respondent, 78% of them demonstrated interest in participating in a DR program, and 81% of them agreed on the benefit it would have on the reduction of CO_2 emissions. Furthermore, 60% of our interviewees considered that giving control to the utility company would be a time saver strategy. People who share a flat showed more of a propensity, while people who live with their parents showed less of it.

The feedback on DR programs for HVAC systems is encouraging as well. The majority of the interviewees expressed a willingness to change the setpoint temperature in a given timeframe, in particular, among people with a higher educational level. Giving away the control of the thermostat raised some concerns, but after considering the possibility of the precooling phase and of the monetary incentives, the rate of people who would not give control to the utility company lowered from 18 to 6%. In particular, more than one-third of people between 26 and 40 years old would be convinced by the monetary compensation, a percentage that is not that high for the other age ranges. On the other hand, around one-fourth of the respondents showed no interest in monetary incentives nor in the free precooling phase, since they would be motivated by a pro-environmental attitude, in particular, in the age ranges 26–60 years old.

About appliances and habits changes, the opinions are influenced by age, home situation, the presence of children, and average income. For instance, people with a net salary that is much above the average would not change most of their habits since they consider it to require too much effort. However, considering the reduced sample size, further research is needed to confirm this hypothesis. The same could be said for the presence of children: in the literature, e.g., in the works [44,45], the presence of small children is related to the difficulty to change the laundry habits, while from our results, this hypothesis was not confirmed. The influence of the age range and the home situation is more reliable, since the sample size of the several categories is comparable. The reluctance in changing habits was noticed, in particular, among people aged from 26 to 40 years old, because of the difficulty to combine it with their schedule, and among people that live on their own. This result confirmed what found by Yilmaz et al. [45], which associated the desire of maintaining daily routines with the age range, affirming that it can be used as a

significant predictor of acceptance. Apart from changing habits, when the single appliances were analysed, the most eye-catching datum is that the proportion of people who accepted a change to their pattern of use was, on average, 61.6% (mean of the several appliances), while that of the acceptance to give control to the utility company was, on average, 41.8%. This is confirmed by the open answers given by some respondents, from which it appears that the interviewees do not feel totally safe relinquishing control, thinking that it would not be necessary, or even that the energy company could take economic advantage of the situation.

4.2. Practical Considerations—Estimated Costs, Revenues and Payback Period for Residential Consumers

This paper aims to give a clearer picture to policymakers and other institutions on the most effective ways to deploy demand response programs. For this reason, the results of the survey were completed with practical considerations.

End user considerations for and approaches to the energy services and technological interventions that can realise and facilitate either energy efficiency services or DR services are addressed by the quantitative analysis presented in Section 2. The acceptance of new technologies that, at the same time, can ensure the achievement of the energy goals and contain, or in some cases, prevent consumer comfort disruption will eventually become the cornerstone for successfully migrating to the status of the active consumer. Yet, important factors for the deployment of energy services and the technology they require are the actual savings or revenues expected for the consumer and the relevant payback period for the investment required to realise these savings. A thorough analysis has taken place regarding the practical implementation, as well as the viability of the interventions, from the point of view of both the aggregator and the Energy Service Company (ESCO).

The ESCO's fundamental business model relies on interventions that can decrease the overall consumption of a household or better exploit the presence of small production units (such as rooftop PV systems through the use of batteries), while at the same time preserving the user's comfort levels. It typically proceeds with the installation of equipment that improves energy efficiency. On the other hand, a demand side aggregator requires sophisticated equipment for the direct control of loads to respond in very short time windows to signals or events from the electricity markets. Control events that are triggered by energy management systems operated by an aggregator usually remunerate the customer explicitly by sharing the revenue gained by participation in the electricity markets.

In order to evaluate the practical economics of such business models, we further detail our considerations on the involved costs and revenues.

The significant upfront costs (Capital Expenditure—CAPEX) of retrofitting is an important factor that affects the decision of a residential consumer and explains, to a certain degree, the reluctance to invest in the relevant equipment and deploy both the energy solutions, as well as the change in electricity consumption habits. These upfront costs depend on the devices and infrastructure deployed in each household.

Specifically, the number of local production assets (such as rooftop PV systems) that need to be controlled has an impact on the upfront costs, yet, at the same time, this creates more space for energy efficiency and flexibility services deployment. Each local production asset, in turn, would require a distinct metering system, as well as a control system, which is not standard in legacy equipment.

In the majority of cases, the basic equipment would require a communications gateway for all the metering and sensor data to be accumulated, and then forwarded to the service provider systems for further processing, as well as for the distribution of control signals or setpoints to the deployed devices. Sensors that measure specific conditions, such as temperature, light, humidity, as well as the presence of sensors are typically deployed for the continuous monitoring of the surroundings. Usually, these are multisensory devices, and no more than three of them would be required for a typical household.

Every controllable load is typically accompanied by a smart meter—which is essential for the actual measurement of savings or flexibility provision—and an actuator for the actual control of the load. Commercial costs for the aforementioned equipment—including installations—have a range of EUR 500–1000 depending on the types and amount of the loads that need to be controlled.

Another cost input is the operational and maintenance cost (OPEX) for the equipment and the services provided by the service provider. The maintenance costs regarding the equipment are relatively low, and the equipment itself is relatively reliable, and as such, insignificant in terms of the OPEX costs. From a service provider perspective though, some recurring costs may incur that are related to general IT infrastructure services such as hosting, data storage, and data security. While the actual cost of the systems for the service provider is diluted according to the number of households involved, it is still expected that an annual amount of EUR 60–120 will be charged to the end user [66].

Table 7 presents some extreme cost scenarios related to equipment and maintenance costs.

Table 7. Cost of equipment and O and M in euros (EUR).

Cost Component	Low-Cost Scenario	High-Cost Scenario
Gateway	200	300
Multi Sensors	30	90
Smart meters	100	200
Actuators	30	90
Installation	100	200
System calibration	50	100

From a revenue viewpoint, there is variability among EU countries in the types and size of the revenue streams that household consumers have access to by participating in electricity markets. The European average consumption per household per year amounts to 3.7 MWh, however, there are significant dispersions among different climatic regions within the continent [67].

Passive energy efficiency measures have been found to yield energy savings of 5–15% depending on the interventions deployed. Additional savings of about 5% can be achieved through the use of price-based scheduling, and self-consumption optimization can offer a further 5% overall saving on an annual basis. As such, an overall 25% reduction of energy consumption can be reached.

Flexibility services create additional revenues in contrast to the cost reduction provided by the energy efficiency measures. Flexibility in households is even more difficult to estimate since it is not a mature or thoroughly regulated service in the majority of the EU markets [68]. According to the existing literature [69], as well as relevant ongoing research [70], a realistic flexibility target for households would amount to about 10% of the overall household consumption. Flexibility, where it is applicable, is compensated by different tariffs than the tariffs applied by suppliers to the consumption component, and they are generally higher than the latter ones or are directly linked to balancing market prices [70]. In France and the Netherlands, where demand response markets have a degree of flexibility, prices varied until the EU energy crisis at 0.10–0.18 EUR /kWh.

Under market circumstances prior to the EU energy crisis, all of the above revenues would typically result in an overall payback period of approximately 8–10 years. Full energy services deployment (energy efficiency and flexibility) corresponds to the high end of investment costs and an 8 year payback period, while minor interventions correspond to the low end of investment costs and a 10 year payback period. For the calculation of the payback period, it is assumed that by utilizing the ESCO model, a proportion of the savings or earnings goes to the service providers and is not fully enjoyed by the final consumer.

Though with the prices of electricity skyrocketing since mid-2021, energy efficiency services have become progressively appealing, while demand side flexibility is regarded as one of the most interesting technologies for system operators [71]. With these considerations and household electricity prices, the payback periods are significantly lower, ranging within 4–6 years accordingly (Figure 5).

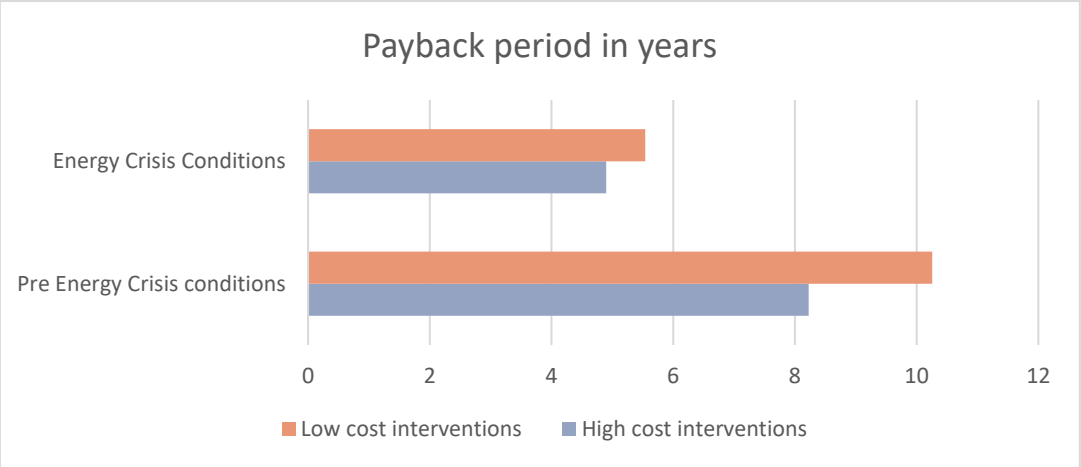


Figure 5. Payback period in years.

5. Conclusions

In this paper, the end users' acceptance of different management types of their energy use is analysed. Through an ad hoc questionnaire, it was possible to collect the opinions of fifty people with different backgrounds on topics such as smart home technologies, demand response programs, changes in habits, and changes in their energy demand. The questionnaire also had a dissemination objective, since several explanation boxes were included to help the interviewees understand the framework.

Smart home technologies are a necessary means to apply demand response strategies. One-third of the respondents already use them, and among the remaining 2/3 of them, a simple explanation of what they are used for (included in the questionnaire) was enough to make the 97% of them interested in trying them. We believe this confirms the importance of information for the spread of the smart buildings. When they were asked to agree or disagree with the sentence "I think smart technologies would steal my personal data", only 40% of the interviewees disagreed: the popularisation of information on how data are collected and used in a smart building could be a key to diminishing people's concerns. Often, what one considers to be a lack of acceptance is actually a lack of knowledge, and informative campaigns could really help to narrow the gap.

Regarding the DR strategies and the change in habits, when one is talking about the idea of participating and enrolling in a program, the acceptance is very high, in particular among women, who showed significantly more disposition. However, when real-life examples and practical situations are presented, the willingness is less clear. In the general section of the survey, the percentage of people that agreed to give control to the utility company was higher than the one of people that agreed to change their habits at their discretion, knowing that it would be more difficult to manage. When they were asked about the single appliances, the results showed the opposite: the percentage of people who would give control to the utility company went from 13% to 27% less than the one of people who preferred to change their habit at their discretion. In other words, a discrepancy exists between the desire to be part of the change and the actual consequences that one is prepared to experience in everyday life. This is in line with what was found in the literature based on real datasets [26], which show that a high percentage of users who enrolled in a DR program somehow sabotage the success of the strategy, probably without even being

aware of it. The conclusion that can be deduced is that it is not enough for energy managers and energy companies to gather subscribers for the DR programs, it is also of primary importance to design an engaging and informative plan that guide and advise the members in their energy behaviour.

The findings of this paper can increase the effectiveness of DR programs, since the differences in the demographic features highlighted can be very valuable when one is designing energy flexibility strategies. Energy flexibility strategies are usually organised by districts, where a district can be seen as a group of people. The division in districts is a means to reduce the so-called rebound effects: if all of the users change their consumption time to avoid a particular peak of consumption, the result will be to simply create another peak at another time of the day. So, what differentiates districts is often merely the time schedule, but the strategy remains the same. We believe that it would be considerably more effective to group the districts according to the features and characteristics analysed in this work. First of all, it would be a direct way to predict the users' behaviour, leading to a more reliable prevision of the actual energy use. Secondly, the energy company can design small modifications to the main energy strategy in order to adapt the latter one based on the district's preferences, which is highlighted in this work. In this way, it would be possible to maximise the acceptance and optimise the energy target.

The preferences and differences discussed can be also used to exploit the potential of incentives and to create targeted campaigns based on the main enabler or motivator (care of the environment, monetary saving, interest in technologies, etc.) for each category. For instance, knowing that living in rental accommodation has a significant influence on considering oneself to be uninformed about how to save energy can be a highly valuable indicator of who to direct informative campaigns at.

Finally, this work addresses the actual payback period of the initial investments required for household consumers to participate in energy efficiency or DR programs. A more practical view of the likely payback time and revenues that they can obtain through these strategies can narrow the gap between the perceived savings and the actual ones, which is reported in the literature as one of the main threats to their effectiveness. Nevertheless, the current energy crisis conditions are providing better incentives for household owners to proceed with the necessary infrastructure, as the returns are significantly higher.

To conclude, here is a brief consideration about the limitations and future research lines. One relevant limitation of the work is the number of respondents who agreed to fill in the survey. As a consequence, the sample sizes were, in some specific cases, unequal. This factor could affect the statistical power of the significance tests such as the one used to analyse the findings. Moreover, the age distribution might have been narrowed by the choice of distributing the questionnaire via email; for future surveys, another distribution method, such as door knocking, should be used. Finally, it would have been interesting to include the considerations about the payback periods at an earlier stage of the work in order to include additional information in the questionnaire and to verify whether or not acceptance is affected. Future works should propose an adaptation of a similar methodology to analyse the acceptance of users that are already enrolled in a DR program to evaluate how and if the subscribers are committed to and engaged with the strategy. In addition, given the good communication that resulted from sharing user-friendly information with the respondent, it would be useful to conduct a comprehensive study on how to best communicate with the user within the new framework of the DR schemes.

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Appendix A

Table A1. Sentences about smart technologies—answers collected on a 5-point Likert scale.

Smart Technologies	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Smart home technologies would allow me to save money	28%	64%	8%	-	-
Smart home technologies would allow me to save time	24%	52%	16%	8%	-
Smart home technologies would give me more commodities	46%	38%	10%	6%	-
I think smart technologies would be difficult to use	4%	4%	12%	62%	18%
I think smart technologies would steal my personal data	10%	24%	26%	28%	12%
I think I could impress my significant others if I had smart technologies	4%	26%	36%	20%	14%
I feel encouraged by my significant others to acquire smart systems	6%	20%	42%	14%	18%

Table A2. Sentences about changing habits—answers collected on a 5-point Likert scale.

Changing Habits	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I experienced disconnections for using many appliances at the same time	12%	36%	16%	24%	12%
With respect to mitigating climate change, I consider that I always try to save energy. The actions of individuals can make a positive difference in global climate change	26%	50%	14%	8%	2%
I never wondered if my energy use was correct or efficient	6%	24%	12%	40%	18%
My cohabitants are committed in saving energy and that affects their habits	8%	36%	42%	6%	8%
I am willing to encourage my cohabitants to change their habits to save energy	22%	60%	14%	4%	0%
I think my social environment is not informed enough about how to save energy	32%	40%	12%	12%	4%
I think I am not informed enough about how to save energy	10%	30%	18%	30%	12%
I would be willing to change my habits if I had an incentive	30%	50%	16%	2%	2%

Table A3. Sentences about demand response programs—answers collected on a 5-point Likert scale.

Demand Response Programs	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I understood what a Demand Response program is	22%	62%	6%	10%	0%
I would participate in a Demand Response program	20%	52%	14%	12%	2%
Demand Response would help me to contribute to the environmental cause	18%	58%	12%	10%	2%
Giving control to the utility would allow me to save time	14%	46%	18%	16%	6%
I'd rather change the consumption at my discretion, even if it is more difficult	12%	32%	28%	28%	0%
I would feel more comfortable if my social environment tried it before	4%	34%	38%	22%	2%

Table A4. Items about the appliances. Note that the percentages refer to the total number of owners of the corresponding appliance.

Appliance	People That Own the Appliance	Acceptance to Change Their Pattern of Use	Acceptance to Give Control to the Utility	Annual Incentive Expected		
				EUR 50	EUR 100	EUR 250
Washing machine	45	62%	44%	24%	24%	16%
Tumble dryer	16	44%	31%	19%	0%	25%
Dishwasher	34	68%	47%	35%	24%	6%
Vacuum cleaner rob.	20	60%	40%	25%	20%	5%
Water heater	19	74%	47%	32%	16%	42%

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