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# The potential of energy behaviours in a smart(er) grid: Policy implications from a Portuguese exploratory study

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## Abstract

The transition to smart grids is an on-going process that may both shape and be shaped by end-users' energy behavioural adaptations. This study explores current and potential energy behavioural adaptations in Portugal during the smart grid transition process. A web-based survey was made to a representative sample of a specific segment of Portuguese residential end-users. The survey evaluated current energy behaviours and hypothetical future behaviours in a dynamic pricing scenario. Results show this population segment has a positive predisposition towards smart technologies and demand shifting, but it is less likely to accept load control and switch to the liberalised energy market. Factors influencing the behavioural potential are mostly related with market regulation, households' practices and usage behaviours, interference with the private domain, information and technical aspects, and social values. To facilitate behavioural adaptations several strategies are recommended, such as improving the energy market regulation, assessing households' behaviours, prioritising actions already embedded in households daily routines, not interfering with their activities and ensure an override option, and improving energy services, trust and information provided to end-users. The conclusions of the present study are of utmost importance for the design of more effective demand response programmes and energy policies.

## Keywords

Energy behaviours, smart grids, demand response, energy efficiency, behavioural change, Portugal

## 1. INTRODUCTION

The decarbonisation of the economy is an indispensable step towards sustainability, and the power industry is a critical part of this process. The evolution towards smart grids is expected to enable the large-scale integration of low-carbon technologies delivering power more efficiently and reliably (EC, 2011; Hledik, 2009; OECD/IEA, 2011b). Furthermore, smart grids and associated technologies are foreseen to enable end-users to have greater management ability over their electricity consumption and actively participate in the electricity market (EU, 2013).

However, the increased complexity in smart grids associated with dynamic pricing schemes, short-term metering, decentralised generation and storage may represent a significant burden for small consumers. Deciding whether to use, store or sell electricity back to the grid in face of dynamic variables such as the price of electricity, weather conditions, comfort requirements, and electricity availability from decentralised renewable sources, is a very challenging decision process for small end-users thus requiring some form of automated support (Chassin, 2010; Livengood and Larson, 2009; Lopes et al., 2012; Soares et al., 2014a).

Technologies that provide this kind of support are considered enabling technologies and include advanced metering, automatic control devices, in-house communication and energy management systems and displays. Although they may help end-users to control electricity consumption they also raise behavioural challenges, which are related to adoption and effective use, willingness to leave decisions to these devices, or even feedback features.

During the evolution process to smart grids, end-users are also expected to have an increasing active role in the management of energy resources as energy co-providers, actively participating in the electricity market (EU, 2013; Foxon, 2013; Geelen et al., 2013; Giordano and Fulli, 2012). This brings a novel dimension to energy behaviours, traditionally only focused on investment, maintenance and usage (Van Raaij and Verhallen, 1983), and to their contribution in promoting energy efficiency. Understanding and foreseeing these dimensions and energy behaviours' role and challenges during the evolution to smart grids is therefore crucial for achieving higher levels of end-use energy efficiency, enhancing demand-side resources and contributing to overall sustainability. This is particularly relevant in contexts where the transition to smart grids and/or electricity retail markets have just recently became visible to the average consumer, such as in the Portuguese context.

### 1.1 The role of people in smart grids

The role of energy behaviours in the context of smart grids is gaining increasing recognition by both policy makers and researchers (Torriti *et al.*, 2010). Literature in this area is diverse and includes social, behavioural, and socio-technical perspectives.

Residential end-users accept smart technologies and support related investments, but are uncertain about their social and individual benefits (Dütschke and Paetz, 2013; Lineweber, 2011; Mah et al., 2012). Therefore, improving communication to residential end-users on the benefits of smart technologies is a key aspect for their deployment (Darby, 2010; Lineweber, 2011). Recent studies also found smart home technologies are adopted or rejected depending not only on their price, savings, and payback, but also on their convenience, ecological footprint, transparency and data privacy, the sense of control they provide, and other design attributes (Balta-Ozkan et al., 2013; Paetz et al., 2012).

End-users also support smart meter deployment, but often overestimate the benefits and abilities of this technology. For example, they usually confuse smart meters with in-house displays or other enabling equipment, thus expecting meters to deliver immediate savings and provide appliance-level feedback about electricity use (which would only be possible when complemented with in-house displays) (Krishnamurti *et al.*, 2012). In fact, in-house displays are important tools to re-materialise energy consumption, contributing to increased energy awareness, although not being sufficient to create enduring efficient energy behaviours (Pelenur and Cruickshank, 2013). Furthermore, end-users perceive smart meters as potentially compromising their privacy and reducing their level of control over electricity usage (Krishnamurti *et al.*, 2012). Data privacy and security issues associated with the exposure of end-users' information, habits and behaviours extracted from electricity monitoring data are the most cited key challenges in smart metering deployment (Clastres, 2011; Darby and McKenna, 2012; Giordano and Fulli, 2012; Krishnamurti et al., 2012; Martiskainen and Coburn, 2010; McDaniel and McLaughlin, 2009; Olmos et al., 2011; Verbong et al., 2013). Positive willingness to pay for smart meters was found to be associated with trust in the protection of personal smart metering data, intention to change energy behaviours and, less importantly, potential energy savings and environmental awareness (Gerpott and Paukert, 2013).

Factors influencing end-users' enrolment in demand response programmes and dynamic pricing schemes include: end-user's level of electricity literacy (e.g., consumption and electricity market), which may be impaired by the “invisibility” of electricity; the complexity of demand response programmes, dynamic tariffs and contracts; the upfront cost of technologies when compared to savings and financial incentives; the effort required to seek dynamic pricing information and reprogram electric appliances accordingly; end-users’ risk aversion; savings expectations and perception of equitable distribution of benefits between the utilities and end-users; and inertia associated with behavioural change, in particular, habits (Alexander, 2010; Chassin, 2010; Darby and McKenna, 2012; Dütschke and Paetz, 2013; Faruqui et al., 2010; Gyamfi and Krumdieck, 2011; He et al., 2013; Kim and Shcherbakova, 2011; Paetz et al., 2012). End-users do respond to dynamic pricing and change how they use electricity, but the magnitude of the response varies depending on several factors, such as their perception of demand response programmes, willingness to enrol, incentives, dynamic pricing structure, presence of enabling technologies and feedback systems, and the social context (Allcott, 2011; Bartusch et al., 2011; Darby and McKenna, 2012; Dütschke and Paetz, 2013; Faruqui et al., 2010; Faruqui and Sergici, 2010; Faruqui et al., 2013; Nyborg and Røpke, 2013; Thorsnes et al., 2012). In particular, the response is stronger when more sophisticated enabling technologies are utilised to support end-users’ actions and decisions, specifically those integrating large volumes of information and automatically reprogramming appliances based on price information (Chassin, 2010; Clastres, 2011; Darby and McKenna, 2012; Faruqui et al., 2010; Ivanov et al., 2013). A crucial factor is end-users’ willingness to leave decisions to these devices. End-users often mistrust full automation and prefer controllable levels of automation (Karjalainen, 2013). Further, they accept these technologies as long as they do not interfere with their daily routines (Paetz *et al.*, 2012). Therefore, the way technologies are embedded in end-users’ daily practices (domestication) is considered very important (Shove and Walker, 2010; Verbong et al., 2013). Attention should be focused on end-users, their energy behaviours, daily routines and the social context in which they live, particularly since changes in social practices may offset energy efficiency benefits brought by smart technologies (Shove and Walker, 2010; Strengers, 2012; Verbong et al., 2013).

One of the most expected behavioural adaptation is end-users shifting from a passive role as electricity consumers to a more active role as co-providers (Geelen *et al.*, 2013). From this perspective, in addition to using electricity, end-users would be involved in the management of energy resources, such as planning or shifting their electricity usage according to their needs and the economic incentives provided, producing electricity through renewable resources, and storing or trading self-produced electricity (EC, 2012; Foxon, 2013; Giordano and Fulli, 2012; Soares et al.). In this new context, end-users are expected to adopt new roles, new responsibilities and powers within the electricity system, thus becoming "energy citizens as opposed to merely economic actors" (Bergman and Eyre, 2011). This change of roles requires a greater involvement of agents in the energy system and higher levels of trust and confidence between end-users and utilities (Gangale et al., 2013; Honebein et al., 2011). This is a major challenge to both utilities and end-users, requiring innovative solutions to trigger this change and guide end-users through it (Gangale et al., 2013; Geelen et al., 2013; Honebein et al., 2011). For instance, smart grid projects in Europe revealed that in the process of turning end-users into more active players in the energy system it is important to tailor and diversify strategies based on end-users' segmentation according to attitudes, motivations towards energy usage, and values (EU, 2013; Gangale et al., 2013). These projects also stressed the need of change how electricity is perceived by end-users while building a trusting relationship with energy providers. However, end-users' behaviours and perceptions during this transition will concurrently be influenced by the social construction of smart grids, in particular their governance models, institutional issues, socio-cultural dynamics, rules, roles performed by energy actors and the organisation of the power system (Verbong et al., 2013; Wolsink, 2012). Accordingly, further empirical social research is fundamental to the successful co-evolution of technology and behaviours, thus enabling the potential of smart grids to foster end-users' active engagement (Geelen *et al.*, 2013). It also fits within the developing area of research on "social potential" to enable energy transitions (Janda, 2014; Moezzi and Janda, 2014).

To summarise, the (socio-)technological transition towards smart grids is an on-going process requiring (and producing) adaptive behaviour by end-users. Smart technologies will facilitate end-users' daily decisions and routines, influencing electricity demand to more efficient patterns. However, the adoption of these technologies is influenced by technical features and demand response is limited by end-users' daily routines, activities and behaviours. Moreover, the deployment of smart grids also enables end-users to be more involved in the energy system and in the management of energy resources. Accordingly, capturing end-users' perceptions and preferences on smart technologies and the management of energy resources is central to unfolding the potential of smart grids.

### 1.2 The Portuguese context

Portugal's economic context, physical electricity system, and retail electricity market are in transition. These contextual factors make it an interesting location for studying current and potential energy behaviours.

Economically, Portugal has been facing a downturn period, with a negative yearly variation of the GNP from 2011 to 2013 (FFMS, 2015) and an increase of unemployment which reached a rate of 16.2% in 2013 (Pordata, 2015).

In 2010/11, a charging network for electric vehicles was implemented with 1,350 smart charging stations accessible to end-users throughout the country (MOBI.E, 2010). In 2013 renewable energy sources contributed 53% of overall electricity production (DGEG, 2014). Several pilot programmes have been implemented by utilities using smart meters and energy management systems, ranging from simple in-house feedback displays to programmable systems endowed with actuation on loads (EC, 2014). However, Portugal has not yet decided in favour of a large-scale smart meter roll-out, thus impairing the European Commission's 80% target penetration rate by 2020. As a consequence, demand response programmes and direct load control activities have only had an experimental basis with limited results.

The liberalised retail energy market was opened to energy intensive activities (such as the industry and services) since 1995, but it was opened to small end-users (residences and small and medium companies) only in 2006. Since 2006 residential customers have had the option of leaving the regulated market and joining the liberalised market by choosing another supplier. A financial stimulus was applied to promote this change: those who remain in the regulated market are subject to tariff increases on a quarterly basis. As in other countries, Portuguese residential customers have been sluggish about switching from regulated supply to the liberalised market. After 8 years of opportunity, 74% of residential electricity customers have switched to the liberalised energy market (ERSE, 2015b). While electricity in the regulated market is supplied by one provider (the "last resource" company), in the liberalised market eleven different companies are currently operating, all accredited by the Energy Services Regulatory Authority (ERSE, 2015a). It is expected the regulated market to finish by the end of 2017 (ERSE, 2015b). Customers in both the regulated and liberalised markets may choose among flat, dual or three level time-of-use tariffs.

Whatever the cause - the recent economic restrictions, the increase of energy prices and/or behavioural changes - Portuguese household energy consumption has decreased in recent years. The households' average primary energy consumption has decreased 17% from 2004 to 2013, moving from 0.82 to 0.67 toe/household.year[1] (excluding vehicles) (DGEG, 2015). Accordingly, this is

[1] Tonne of oil equivalent per household per year.

an important moment to assess current energy behaviours of Portuguese end-users and consider their future potential for involvement in the emerging smart grid context.

### 1.3 Objectives and research questions

Most research about demand response is based on modelling fictive circumstances to provide general estimates of technical and economic potential (Du and Lu, 2011; Haoa et al., 2015; Soares et al., 2014a). Alternatively, experimental approaches based on studying pilot projects, often with small, non-representative samples are developed (Gangale *et al.*, 2013). In contrast, this study uses empirical research methods to explore behavioural potential. The research is therefore necessarily located in a specific time and place, and assesses the willingness of people rather than the ability of things. It characterises current energy behaviours and considers future behavioural adaptations of end-users to the smart grid through a web survey performed in July 2013 in Portugal to a representative sample of a specific population segment. It also explores end-users' preferences towards enabling technologies, thus contributing to empowering end-users as co-providers in smart grids, as recommended by Geleen *et.al.* (2013).

This study was developed in the context of a multidisciplinary project developing a demand responsive energy management system (Energy Box) to be used to control, manage, and optimise smart grid technologies and home electricity use (http://www.uc.pt/en/org/inescc/Projects/energy_box). This system aims to autonomously coordinate and optimise electricity management for small end-users, including storage and selling back to the grid (Chassin, 2010; Livengood and Larson, 2009; Lopes et al., 2012). For this purpose, users' preferences need to be properly understood and addressed, including constraints associated with household behaviours, the use and shifting of domestic loads, decentralised renewable generation and electric vehicles. This study is grounded on a technological perspective integrating behavioural knowledge from the social sciences.

The main research questions associated with the present work are: How are Portuguese residential end-users adapting to changes brought on by the emerging smart grid? What are the relevant factors for facilitating further behavioural adaptation in Portugal? And what are the preferences towards a demand responsive energy management system? A literature review was presented indicating that smart grid deployment generates (and, at the same time, requires) behavioural changes, together with a discussion about the expected evolution of the Portuguese energy system and economic context. The present study explores highly-qualified end-users' current behavioural adaptations, as well as their preferences for adopting enabling technologies in the future, such as the demand-responsive energy management system mentioned above. Ultimately, this study aims to contribute information to help policy makers, utilities and other stakeholders designing interventions and energy policies to facilitate the on-going transition to smart grids.

## 2. METHODS

### 2.1 Studying behaviours

For the purposes of this study, we consider energy behaviours to be observable acts related to energy consumption and include investment, maintenance, and usage behaviours (Van Raaij and Verhallen, 1983). Investment behaviours involve the purchase of new equipment; maintenance behaviours involve the repair, maintenance and improvement of energy consuming equipment; and usage behaviours refer to the day-to-day utilisation of buildings and equipment. In the context of smart grids, energy behaviours also comprise actions required to manage energy resources (e.g., leading to producing electricity through small generation technologies or storing electricity in electric vehicles) (Geelen *et al.*, 2013).

Research on residential energy consumption may use qualitative tools such as surveys, interviews, focus groups or other form of survey-based methods collecting data on end-users' behaviours (Crosbie, 2006). There are limitations to using surveys for assessing behaviours, since real-life conduct can diverge considerably from statements made in answering a survey (Gangale *et al.*, 2013). Moreover, a household's future response to imagined situations and technologies is difficult to assess through an a priori standardised questionnaire. Survey questions also unavoidably produce framing effects (Van de Velde *et al.*, 2010), which limit both the shape of respondents' answers and the conclusions that can be reliably drawn from them. Despite these limitations, questionnaires are a common tool used in research exploring both existing and hypothetical scenarios, such as the willingness to pay (Hansla, 2011). They reach a large number of respondents in a short amount of time, are a familiar tool, and are less intrusive than other exploratory methods. For these reasons, a web-based survey was selected as the main research method. Although expert sampling could be an alternative technique to be utilised in this research to avoid the limitations of surveys, the research was intentionally based on a purposive non-probability sample to collect the opinions of a large number of non-experts considered to be the target population. As non-probability sampling was not used to perform statistical inferences from the sample to the wider population, and only descriptive statistics was applied, no bias exists.

### 2.2 Survey sample, delivery and responses

In 2013, the percentage of Portuguese residents with a higher education degree represented 15% of the overall population (Pordata and INE, 2015). In the same year, the total number of higher education teaching staff in Portugal was estimated to be 33,582 people (Pordata, 2014), and the full set of potential respondents covered about 24% of this population segment. The use of this sample limits the extrapolation of these results to the overall population. Nevertheless, studying this educated sample provides a vision of a relevant population segment, i.e. typical "early adopters" on the diffusion curve of technological innovations (Rogers, 2003).

This population segment has an income level above the national average, and wide-ranging access to the internet (mobile and at home). We assume that literate groups have a higher savings potential than the average citizen, are more likely to acknowledge the importance of energy efficiency, are more receptive to smart grids and associated technologies, and thus more willing to participate in a research on this topic. These characteristics also contributed to improve the rate of answers since web-based surveys possess a low rate of answers in less educated samples (Divard, 2013). The survey was presented to participants through e-mail and a web platform to facilitate respondents' participation (since they use e-mail and web on a daily basis) and to minimise data treatment errors.

The survey was performed during June and July 2013 to a sample of 8,000 professionals from higher education institutions (mostly composed of university faculty members) through e-mail contacts and further expanded through a snowball strategy. Hence, it is not possible to estimate the final number of professionals reached. A total of 1,612 answered surveys were received (circa 20% response rate), representing 4.8% of the total Portuguese higher education teaching staff. Surveys lacking more than 5% of answers were eliminated, making a total of 1,084 surveys analysed. In this exploratory study results were treated using descriptive statistics and questions lacking more than 5% of answers were not considered.

### 2.3 Survey design

The survey included 44 questions mostly using a closed format (some open questions were also performed). It covered basic socio-demographic and geographic variables, then asked respondents about current behaviours and possible future behavioural adaptations to the smart grid and associated technologies (Table 1, Table 9 in appendix).

Current behaviour questions addressed a range of energy behaviours, energy beliefs and literacy, participation in the liberalised electricity market, the effects of the economic crisis on energy behaviours, and the adoption of smart grid technologies. In this study, current energy behaviours were characterised using a selected list of self-reported energy usage, investment, control and monitoring behaviours. Respondents were asked to assess the frequency energy behaviours were performed in the household in the last year. Questions used a 5-point Likert scale when assessing variables in relation to frequency, importance, availability, flexibility, probability and agreement.

Preferences concerning hypothetical smart grid technologies, demand shifting, and direct load control were assessed for a future smart grid scenario. The complexity associated with this scenario was simplified in the questionnaire since the smart grid topic is still unfamiliar for the majority of end-users. Hence the smart grid expression was not presented to respondents and, as an alternative, they were presented with a hypothetical future scenario of dynamic pricing of electricity (having an hourly variation) (Table 1, Table 9 in appendix).

[INSERT TABLE 1 HERE]

## 3. RESULTS AND DISCUSSION

### 3.1 Socio-demographic characteristics

The respondents (N=1,084) had an average age of 46.87 years ($\sigma$=9.53)[2], 55.4% were men and 43.6% women. The majority of respondents were highly educated (97.7% had a higher education degree, which contrasts with the national value of 15.0%), 93.1% were employed in highly qualified professions (e.g., teaching staff) and 72.6% married. The sample was geographically spread in the country, with 17.3% from the north, 53.0% from the centre region, 26.2% from the Lisbon urban area, and the remaining 3.5% from the south region and islands. The composition of respondents' household was not characterised, which constitutes a limitation of this study. However, considering the

[2] The average age of the Portuguese population in the last census (2011) was 41.83 years old. INE, 2013. Average age of the Portuguese population in 2011, 09/03/2013 ed. National Statistics Institute.

respondent's age, marital status and income, it is expected households to be composed by two adults with the possibility of having small children[3].

### 3.2 Current energy behaviours

#### 3.2.1 Frequent behaviours

Results show households frequently engage in twelve different energy usage, control, and investment behaviours. Answers to these questions used a Likert scale with 1="never" and 5="always". Across all respondents and behaviours, the results show a mean of 4.65, corresponding to a very frequent practice (Table 2). There are, however, two less frequent energy behaviours: providing meter readings to the utility and buying more efficient equipment. 76.0% of respondents stated they read the electricity bill "frequently or even "always". However, they rarely provide meter readings to the electricity supplier (only 32.6% stated "frequently" or even "always"). According to the Directive 2009/72/EC, 80% of end-users are expected to be equipped with smart metering systems by 2020 (EC, 2009). However, the majority of Portuguese end-users still possess meters requiring manual readings (either performed by the utility technicians or end-users) to enable more precise billing. Reasons may be associated with a potential lack of time to perform this task, reduced level of importance attributed to it, or disinterest since it is performed by the utility at least once a year. These and other motives should be assessed in future developments of this work.

[INSERT TABLE 2 HERE]

#### 3.2.2 Literacy and beliefs

Results show respondents have a general positive perception about saving electricity and are aware of its importance to the economy (83.9% stated "totally agree" or "agree"), the power grid management (72.9%) and the environment (97.4%) (Table 3). They also recognise their own responsibility in this process (92.8%) and consider saving electricity to be compatible with their daily lives, neither disrupting home activities nor generating inconvenience (56.7% stated "disagree" and "totally disagree" to disrupting the household daily activities; and 62.5% to spend too much time performing these activities).

[INSERT TABLE 3 HERE]

[3] The average composition of a Portuguese household in 2013 was 2.6 individuals. Pordata, INE, 2015. Average dimension of households. Pordata.

### 3.2.3 Current economic context

The majority of respondents (56.9%) stated they have not changed the way of using electricity in their households due to the economic context. The main reason given was related with their beliefs of already saving as much electricity as possible. This motive, also found by previous studies (Gouveia *et al.*, 2011), may be invoked by a gap on specific information on how to save energy and increase energy efficiency levels. It further may be due to the inertia of changing behaviour.

The remaining 43.1% of respondents stated they did make changes to their electricity use due to the economic context. Specific energy behaviour changes comprised (Figure 1): curtailment actions (72.8%); shifting the use of electricity to cheaper periods (42.6%); investing in more efficient appliances (34.7%); reading the electricity bill or the meter (31.0%); altering the contract to change the electricity tariff (18.6%) and contracting a lower power value[4] (8.4%); adopting renewable energy resources (7.7%); and making home improvements (4.7%). Curtailment actions consisted in a general effort to reduce the use of appliances, although they were not specified. Other measures indicated by respondents in the open format questions included switching energy suppliers, switching fuels, using enabling technologies (such as in-house displays and programming devices) and implementing passive actions to promote thermal comfort.

INSERT FIGURE 1 HERE

End-users are mainly performing curtailment to reduce consumption, but they are also implementing efficiency measures to use electricity in a more rational way. Solutions requiring larger investments such as the adoption of small-scale renewable energy sources or home improvements (e.g., double glazing) are implemented in a lower scale, probably due to financial restrictions. Although it is not possible to estimate the level of savings associated with these behavioural adaptations, results are in consonance with Portuguese energy statistics indicating a reduction of 17% of households' energy consumption from 2004 to 2013 (DGEG, 2015).

[4] In the Portuguese residential sector low voltage electricity may be supplied through eight power levels ranging from 3.45 to 20.7 kVA. Very often consumers contract a higher value than they need, which constitutes an opportunity for economic savings.

### 3.2.4 Participation in the liberalised energy market

Enrolling in the liberalised energy market constitutes an indication of end-users' involvement in energy provision activities.

In July 2013[5], 33.5% of the survey respondents had enrolled in the liberalised energy market. Compared with the national enrolment rate of 46% at the same time (ERSE, 2013), this shows respondents were roughly 25% less likely to join the liberalised energy market than the average population.

The main barriers invoked by respondents who have not enrolled in the liberalised retail energy market (61.9%) to justify their inaction comprised the lack of information (stated by 40.5%), inexistence of motivating prices (33.5%), satisfaction with the prevailing supply conditions (23.7%), lack of trust in energy suppliers (14.8%), peer influence (7.2%), and unawareness of the liberalised energy market (4.8%) (Figure 2). Even though 77.9% of respondents were aware of the dissemination campaign implemented by the national consumers association, only 6.8% of those joined the liberalised market under this campaign.

INSERT FIGURE 2 HERE

In fact, although the majority of the respondents (95.2%) was aware of the mandatory need of changing into the liberalised market - a more recent national wide study refers a similar value, 93% (Accenture, 2014) - 40.5% referred the lack of information as a barrier. Savings was indicated as the second motive. Although this was not further explored in this study, a recent research referred Portuguese consumers to be dissatisfied with the price of energy, also indicating competitive offers as being one of the main motivations to adhering to the liberalised market (Accenture, 2014). Trust was pointed out as the third reason, which is in accordance with previous research on the need of change the relation between consumers and utilities, particularly emphasising trust and credibility (Darby, 2010; Gangale et al., 2013). However, a more active role in the energy market consists not only in leaving the regulated energy tariffs and contracting energy within the liberalised market, but also frequently changing the energy supplier in face of competitive offers. Recent assessments have revealed Portuguese consumers have not yet internalised this practice since only 3% of residential consumers within the liberalised market have changed their energy suppliers more than once (Accenture, 2014).

[5] Period of implementation of the survey.

Future improvements of this work should also assess other influencing factors for enrolling in the liberalised energy market and switching energy suppliers, such as the bureaucracy associated with the process, behavioural inertia, availability of time - particularly since this task is referred to be time-consuming by studies on early adopters (Nygrén et al., 2015), detail of information and support provided, and how much competitive offers should be to promote the enrolment or the change of suppliers.

#### 3.2.5 Adoption of smart grid technologies

The transition to smart grids also comprises the increasing adoption by end-users of technologies such as demand-responsive enabling technologies, electric vehicles and local micro-generation. Results revealed only 7.0% of respondents used electricity monitoring devices (e.g., in-house displays) despite being particularly aware of their energy consumption (76.0% of them stated to read the electricity bill “frequently” or “always”).

Less than one third (28.7%) currently use time-of-use controlling functions on their appliances (e.g., programming or time-delaying). The most frequently controlled appliance is the laundry machine (by 15.4% of respondents), followed by the dishwasher (12.0%), the electric heating system (9.4%), the water heating system (5.8%), and to a lesser extent the tumble dryer (3.2%) and the air conditioning system (1.9%) (Figure 3). These results are similar to Stamminger and Anstett (2013) findings, where one third of their sample used the start-time delay function of their appliances. However, the results of this study were influenced by the ownership rate of appliances and their technical functionality, which were not characterised in this survey. National statistics indicate the following ownership rates: laundry machine 91%, dishwasher 41%, tumble dryer 19%, air conditioning system 7%, electric water heater 3% (INE and DGEG, 2011). Hence, appliances ownership must be considered when assessing the potential for adopting demand-responsive enabling technologies. Nevertheless, these results illustrate that almost one third of respondents already plan their electricity usage and shift it when appropriate to benefit financially from different existing time-of-use electricity tariffs.

INSERT FIGURE 3 HERE

Only 3.0% of respondents were both consumers and producers of electricity (prosumers). However, this value is 15 times higher than the national rate of 0.2% (MEE, 2014). Similarly, 3.1% also owned an electric or hybrid vehicle, a value at least 30 times higher than the national ownership rate of less than 0.1% (MEE, 2014). These higher rates may be due to the higher income levels and environmental awareness of this population segment, thus confirming their profile as early adopters.

### 3.3 Facilitating future behavioural adaptations

#### 3.3.1 Adopting an Energy Box

When facing a future hypothetical scenario with an hourly change of the electricity price, 71.0% of respondents stated they would be willing to purchase an automated control device (such as the Energy Box) to help them control their electricity use.

A number of factors would, however, influence this purchase (Table 4). Respondents indicated it was “very” to “extremely important” the device would cause no damage to appliances (95.3%), save energy and reduce energy costs (93.9%). Respondents also wanted to have full control of the device (87.9% stated to be “very important” and “extremely important”), expected it would be easy to install and use (80.7%), have a low cost of acquisition (82%), provide useful information (86.9%), and have a user-friendly interface (74.4%). Less importance was attributed to the design factor (only 18.4% stated to be “very important” and “extremely important”). These results further detail factors for adopting smart home devices previously explored by Paetz et al. (2012).

[INSERT TABLE 4 HERE]

Respondents were also asked to assess the importance of potential functionalities of this device (Table 5). All the functional options provided were considered at least “very important”: real time information on consumption and cost (64.9%), and on control of appliances (67.1%); turning appliances off (78.8%); eliminating stand-by consumption (70.2%); and automated programming to shift consumption (73.7%) and to save electricity (73.6%). Preferred functionalities were mainly focused on maximising savings rather than feedback features, which should be considered in the development of the Energy Box.

[INSERT TABLE 5 HERE]

Given the equivalent level of importance respondents placed on both purchase decisions and functionalities, future research should consider alternative methods to elicit preferences to improve discrimination (e.g., ranking, limiting options), bearing in mind the limitations when capturing preferences in future scenarios. Nevertheless, results showed a positive predisposition towards smart technologies, particularly in a context of dynamic pricing, which reinforces previous research

(Krishnamurti et al., 2012; Paetz et al., 2012), while unveiled specific preferences that are essential for designing user-friendly enabling devices and empowering end-users' interaction with the smart energy system.

### 3.3.2 Willingness to shift demand and adapt household routines

Shifting demand may involve changing household activities and their routines. Although the majority of the smart grid literature assumes end-users are responsive to economic incentives, this study explored other decision factors.

When asked about their willingness to change the time-of-use of their appliances, 68.1% of respondents stated they would be available to perform that change, even without any direct benefit (this value increased to 78% when considering those respondents who already shift their use). For example, this percentage was much higher (98%) in a German study in which savings would be generated (Stamminger and Anstett, 2013).

The shifting potential of the following specific appliances was considered: the laundry machine, the tumble dryer, the dishwasher, the electric water heater, the air conditioning system and electrical heaters (Soares et al., 2014c). Only the willingness to shift the laundry machine and the dishwasher could be analysed, since the other appliances had missing responses rates above 5%. The potential to shift the time-of-use of both machines was high: 72.1% and 75.3% of respondents stated to be "flexible" to "extremely flexible" in shifting laundry and dishwashing, respectively. This high feasibility is probably due the specific characteristics of these activities. For example, the laundry and the dishwashing can be performed at night, or when the users are away. Shifting these practices may already be embedded in the daily routines of households with a dual/three time-of-use tariff. Hence, during the transition to smart grids demand response programmes may prioritise familiar actions to end-users while gradually introducing less common actions.

Although similar at some points with Stamminger and Anstett (2013) findings, these results differ on the preferred appliances for demand shifting, namely in relation to the tumble dryer that was indicated as one of the main shifting appliances in Germany (which does not occur in our study). Differences between ownership rates may justify these differences, thus reinforcing the role of this factor in the design of demand response programmes.

In general, most important decision factors for accepting demand shifting included electricity savings (considered at least "very important" by 91.3% of respondents), not compromising the energy service

(82.8%) and environmental benefits (77.8%) (Table 6). Not interfering with the domestic activities (66.2%) and electricity security (63.7%) were considered of medium importance. The presence of the householders at home when appliances are switched on was considered the least important factor (36.8%). The motives underlying the unwillingness of respondents to shift demand also reflected the importance given to electricity savings and to not compromising neither the energy service nor households activities, although with a lower importance, which may suggest hidden motives requiring to be addressed in future developments of this work. The presence of the householders at home when appliances are switched on was considered a more important factor for those respondents unwilling to shift their demand, thus indicating this to be a relevant factor to be considered.

Although results show demand shifting in this population segment to be responsive to economic motives such as savings, it is also strongly influenced by the compliance with household activities and some sense of control over appliances, as well as environmental benefits and security of electricity supply. These results provide further insights on previous research, which only indicated savings, environmental benefits and comfort as the main motivational factors for demand shifting (Gangale *et al.*, 2013).

[INSERT TABLE 6 HERE]

The majority of respondents (89.4%) stated they would change the way they use electricity in face of a future hypothetical scenario with an hourly change of the electricity price. From the list of behaviours potentially to be adopted (Table 7), respondents revealed preferring load shifting (considered at least "very likely" by 85.4%) and using control devices (59.8%) rather than paying attention to electricity prices (41.6%) or adopting decentralised renewable energy sources (25.3%). Only 20.9% were willing to accept load shifting performed by the utility. While attention to dynamic electricity prices may result in information overload thus leading end-users to more convenient solutions such as using enabling technologies to load shifting, end-users prefer maintaining their own control not allowing utilities to perform load shifting through direct load control actions. These results also suggest end-users' preferences towards lower cost investments, rather than higher investments such as microgeneration equipment using renewable energy sources.

[INSERT TABLE 7 HERE]

The motives invoked by 10.6% of respondents for not changing their behaviours were mostly related to the belief that the effort required to change would outweigh any potential advantages (mean 3.42,

$\sigma$=1.10). This group also noted changing electricity usage had limitations associated with the household routines (mean 4.05, $\sigma$=0.82). In fact, electricity is used to provide energy services required by the household activities, which, having specific dynamics, may constrain changes and impose shifting limitations to be considered in demand response programmes.

Strategies aiming to facilitate the willingness to shifting energy demand should prioritise actions performed by end-users in their daily routines and gradually introducing less common actions, while ensuring energy savings and no interference with household activities. A previous detailed understanding of households' practices and behaviours, appliances ownership and assessment of shifting potential is paramount. In this population segment enabling technologies may facilitate this process as far as end-users maintain the control over control actions. This is important information to the design and development of enabling technologies such as the Energy Box.

Future developments of this work should consider other exploratory tools (e.g., open format questions and interviews) to unveil hidden factors associated with shifting demand and further explore end-users' demand shifting flexibility.

### 3.3.3 Enabling direct load control

End-users' availability to accept load control actions over appliances (shifting time-of-use, turning off, redefining operational settings) was explored (Soares et al., 2014c). The majority of respondents (65.1%) was not willing to accept direct load control from the utility, even in a hypothetical future scenario of dynamic pricing. Only 34.9% were willing to accept control of their appliances by the utility. The minority of respondents willing to accept load control was more willing to accept shifting the laundry machine (mean 4.15, $\sigma$=1.02) and the dishwasher (mean 4.16, $\sigma$=0.98) than to redefine the settings of the fridge or the freezer during most expensive periods (mean 3.25, $\sigma$=1.31). Again, already embedded practices such as shifting the laundry and the dishwashing are prioritised in favour of less common actions. The reduced flexibility to redefine the settings of the fridge/freezer may be originated by the belief that these actions may damage refrigerated and frozen food. For utilities to travel this path, additional evidence needs to be provided to assure end-users that there is no potential danger to their food from small changes to refrigeration cycles.

Both the unwilling and the willing groups considered all the decision factors provided as "very" to "extremely important" to justify their decision, although there were some differences between both groups (Table 8). While the "willing group" attributed less importance to the security of electricity supply, to the “unwilling group” the most relevant factors were the override option, privacy issues, feedback about control actions, the existence of a pre-existing agreement to performing these actions, and the potential interference with the household activities. In the latter group, the risk of damaging appliances, electricity savings and trust in the utility were less important decision factors to accept direct load control.

The interference with the private domain arises as one of the most relevant decision factors when assessing the willingness to accept load control. Although this is aligned with the prevailing literature (Krishnamurti et al., 2012; Paetz et al., 2012), further specific dimensions were assessed that require to be taken into account in the design of demand response programmes. Future developments of this work may also utilise other exploratory tools to both eliciting potentially compromising dimensions and motivating end-users to accept direct load control.

[INSERT TABLE 8 HERE]

Moreover, although from a technical point of view water heating and air conditioning systems are also considered interesting appliances to be controlled under load control interventions, the ownership rate of these appliances in Portugal is very low: 3% and 7%, respectively (INE and DGEG, 2011). These ownership rates significantly limit the use of these appliances in real and large-scale interventions. In addition, the way households utilise air conditioning systems may also influence load control actions and limit load control savings potential. For example, only 12.2% of respondents owning air conditioning systems stated always keeping it turned on in a constant temperature, while 38.6% always turned it on temporarily for cooling or heating a room. Accordingly, both appliances ownership rates and usage energy behaviours are important variables to be assessed when designing effective demand response programmes.

Similarly to demand shifting, load control programmes should also prioritise control actions already performed by end-users in their daily lives. Less common control actions should be previously presented and explained to end-users and gradually introduced through pilot groups, while providing detailed feedback. Furthermore, strategies to foster the willingness to accept load control should improve the building of trust between end-users and the electricity utilities (through, for example, increased transparency, personalised services, detailed contracts specifying authorised load control actions or even creating insurance policies to compensate possible damages), and providing detailed information on the control actions, both before and after controlling events. Load control actions should also be programmed not to interfere with the household activities, and an override option should be always provided to end-users. From the regulator perspective, rules should be established and publicised to guarantee end-users' rights and avoid potential misuse of load control.

## 4. CONCLUSIONS AND POLICY IMPLICATIONS

The transition to smart grids is an on-going process that may both shape and be shaped by end-users' energy behaviours. This study used a web-based survey to explore the potential for behavioural adaptations of a statistically representative sample of a segment of Portuguese society, highly educated and with above average income, as a good proxy for early adopters of smart grid technologies. The results of this survey give an empirically grounded indication of how the smart grid in Portugal will unfold, as well as useful insights for future research.

Enrolling in the liberalised energy market is generally considered to be essential for the deployment of demand response programmes in smart grid contexts (OECD/IEA, 2011a). Results have shown this segment has a participation rate in the liberalised retail energy market 25% lower than the national value, so from this indicator our assumption about this sample's participation in the smart grid was not supported. Factors influencing the enrolment process of this segment of early adopters were identified which may also influence other population groups. Further research is required to disclose other motives influencing the lower participation rate of this highly educated and with above average income group. Nevertheless, results have shown that facilitating end-users' involvement in energy management activities require strengthening the market regulation to improve transparency and end-users' protection, provide detailed and tailored information on the process and consequences of changing energy suppliers, use opinion makers as peer influence, and offer competitive and personalised services.

During the transition to smart grids it is also expected end-users to increase their adoption of smart grid technologies. Energy management systems, in particular, are expected to help end-users to manage energy resources and reduce their energy bill, with potential savings that may reach 24% (Soares et al., 2014b). This study showed this market segment has a positive predisposition towards smart technologies, with a significant higher ownership rate of microgeneration installations based on renewable energy sources and electric/hybrid vehicles than the national average, as expected for early adopters. Moreover, this segment already acknowledges the usefulness of smart technologies and uses them when required to minimise energy bills. Considering this population segment has a higher income than the average population, economic incentives should be utilised to promote the adoption of these technologies among less privileged segments of the population. Furthermore, results on the elicitation of preferences suggest the importance of manufacturers developing different enabling technologies, namely energy management systems to control and optimise energy consumption and in-house displays to provide feedback on energy consumption.

Shifting demand will expectedly be at the centre of demand response programmes in smart grids, potentially promoting savings around 28% (Stamminger and Anstett, 2013). The particular segment of early adopters self-reported performing this action frequently. Based on the assessment of preferences performed, facilitating the willingness to shifting energy demand should prioritise actions usually performed by end-users and gradually introduce less familiar actions, while ensuring their preferences are met. When designing demand response programmes, the preliminary assessment of end-users' practices, usage behaviours and appliances' ownership are required to accurately evaluate the load shifting potential. It must be kept in mind that there is a limit to load shifting potential, which is imposed by end-users' living standards and daily dynamics.

Direct load control performed by the utilities was not very well accepted among this segment of early adopters. Willingness to accept load control was found to be influenced by several factors, namely the type of load control and the target appliance, interference with the private domain, feedback and social values. Strategies to facilitating direct load control among this segment should prioritise the regulation of load control actions, protecting end-users while enabling the proper functioning of the energy market. Electricity utilities should reinforce the relationship with end-users, promoting trust, prioritising familiar actions and providing tailored feedback, while guaranteeing effective savings.

To sum up, this study has contributed to the current literature by exploring Portuguese residential end-users behavioural adaptations to the smart grid, identifying the most relevant factors and strategies for facilitating this behavioural change and detailing preferences towards smart technologies and demand response actions. These results are of utmost importance for the design and development of smart technologies as enablers and facilitators of end-users' daily lives in the smart grid (such as the Energy Box), and the design of more effective demand response programmes and energy policies. Although these results are applicable to a particular segment of the Portuguese population, they are not generalizable to the overall population. Nevertheless, these results provide important clues to be considered by regulators and utilities when addressing other segments of the population, since the preferences elicited may not be exclusive of this segment of early-adopters and be also relevant to the general Portuguese population. Hence, further developments should consider expanding this exploratory study to the overall Portuguese society while complementing surveys with other tools (e.g., interviews, surveys with more open format questions, conjoint analysis) to further detail decision factors, unveil hidden elements and elicit end-users' preferences. Moreover, since the survey mainly assessed the willingness to engage into certain actions, not assessing the actions themselves, future research should also include the evaluation of effective actions through the cooperation with real-world smart grid projects. Future research should also improve the statistical analysis by using inferential and multivariate statistics to segment groups and preferences. Finally, this research should lay the foundation to develop an analysis framework of behavioural adaptations in smart grid contexts.

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## APPENDIX

[INSERT TABLE 9 HERE]

## LIST OF TABLES

**Table 1. Survey structure and design**

| COMPONENTS | | DESCRIPTION |
|---|---|---|
| | **Socio-demographic characteristics** | Gender, age, marital status, education level, professional activity, employment status. |
| | **Geographical location** | Postal code identification. |
| **Current Energy Behaviours** | **Energy behaviours** | Frequency of performing specific behaviours such as: efficient use of lighting and appliances; characterisation of the current use of the air conditioning system; investment in efficient equipment; use of passive techniques to improve thermal comfort; shifting appliances to cheaper periods; monitoring electricity consumption; involvement of the household. |
| | **Beliefs and literacy** | Beliefs on energy savings (responsibility, consequences to the environment and the economy) and energy literacy (advantages of energy efficiency), adapted from (Black *et al.*, 1985). |
| | **Influence of economic crisis on energy behaviours** | Identification of energy behaviours which have changed: use of appliances, reading the electricity bill and the meter, change of the electricity contract (power, tariff), shifting appliances to cheaper periods, buying efficient equipment, home improvements, use of renewable energy sources. |
| | | Identification of motives for not changing (limitations to change such as need and effort). |
| | **Participation in the liberalised retail energy market** | Change of the energy supplier and associated motives, knowledge of dissemination campaigns on this topic. |
| | **Current adoption of smart grid technologies** | Use of electricity monitoring and controlling devices, controlled appliances.<br>Adoption of hybrid or electric vehicles and of small generation systems based on renewable energy sources. |
| **Behavioural Potential** | **Adoption of hypothetical smart grid technologies** | Willingness to adopt an automatic controlling device when facing a hypothetical dynamic pricing scenario (decision factors involved, preferred functionalities and controlled appliances). |
| | **Flexibility for demand shifting and change the household routines** | Willingness to change the time of use of electrical appliances, factors involved in this decision (e.g., savings, environment, being at home, electricity supply, energy services provision, and interference with home activities). |
| | **Willingness to accept load control** | Willingness to accept direct load control performed by the utility, both in the present context and in a hypothetical smart grid scenario (namely dynamic electricity pricing). Decision factors involved (e.g., damaging equipment, override, savings, privacy, trust, information, guarantees, interference with home activities, environment, energy supply), types of control and preferred appliances (laundry machine, dishwasher, tumble dryer, and water heating system). |

**Table 2. Characterisation of energy behaviours (1="non-applicable", 2="never" to 6="always", N=1,084)**

| Category | Self-reported energy behaviours | Mean | σ |
|---|---|---|---|
| Usage | Switching off the lights in empty rooms | 5.59 | 0.58 |
| | Keeping doors and windows closed when they are being warmed or cooled | 5.39 | 1.01 |
| | Switching off TV when nobody is watching it | 5.22 | 0.85 |
| | Switching on heating/cooling equipment only on occupied rooms | 5.26 | 1.23 |
| | Switching off appliances directly on the switch to avoid stand-by consumption | 4.70 | 1.24 |
| | Insulating windows and doors | 4.69 | 1.42 |
| | Switching off appliances using central plugs to avoid stand-by consumptions | 4.30 | 1.41 |
| | Switching on washing machine/dryer during the cheapest periods | 4.13 | 1.98 |
| Control and monitoring | Reading the electricity bill | 5.11 | 1.08 |
| | Talking with the dwelling occupants about electricity consumption and savings | 4.02 | 1.53 |
| | Providing the meter readings to the electricity supplier | 3.60 | 1.54 |
| Investment | Buying more energy efficient equipment | 3.78 | 2.20 |

**Table 3. Assessment of personal determinants on saving electricity (1="totally disagree" to 5="Totally agree", N=1,084)**

| Determinants | Saving electricity… | Mean | σ |
|---|---|---|---|
| Energy literacy | …improves the environment | 4.64 | 0.56 |
| | …contributes to energy security by minimising energy imports | 4.38 | 0.71 |
| | …improves the national economy | 4.23 | 0.83 |
| | …improves the power grid management | 3.98 | 0.81 |
| Beliefs | … is a societal obligation | 4.54 | 0.68 |
| | …represents economic advantages to the household | 4.38 | 0.62 |
| | …begins with my example | 4.37 | 0.72 |
| | …is a consumer responsibility | 4.12 | 0.81 |
| | …disrupts household daily activities | 2.50 | 0.98 |
| | …spends too much of my time | 2.30 | 0.93 |
| | …implies a lifestyle with reduced comfort | 2.20 | 0.94 |
| | …creates more disturbance than it generates benefits | 2.06 | 0.86 |

**Table 4. Assessment of factors influencing the potential purchasing of an "Energy Box" (1="not important" to 5="extremely important", N=1,084)**

| Influencing factors | Mean | σ |
|---|---|---|
| Causing no damages to appliances | 4.70 | 0.57 |
| Saving electricity and reducing costs | 4.54 | 0.62 |
| Full control of the device | 4.46 | 0.73 |
| Low cost of acquisition | 4.36 | 0.78 |
| Quality of the information | 4.35 | 0.73 |
| Trust in the technology | 4.34 | 0.72 |
| Easiness of installation & configuration | 4.22 | 0.79 |
| Easiness of use | 4.20 | 0.81 |
| Portfolio of functionalities | 4.10 | 0.79 |
| Friendly interface | 4.10 | 0.82 |
| Design | 2.63 | 1.05 |

**Table 5. Assessment of functionalities of an "Energy Box" (1="not important" to 5="extremely important", N=1,084)**

| Functionalities | Mean | σ |
|---|---|---|
| Turning off appliances | 4.19 | 0.91 |
| Automated shifting of appliances to cheaper periods | 4.07 | 0.93 |
| Automated programming to save electricity | 4.03 | 0.95 |
| Eliminating stand-by consumption | 3.97 | 0.98 |
| Feedback on load control | 3.94 | 0.93 |
| Real time feedback on electricity savings | 3.90 | 0.94 |

**Table 6. Decision factors influencing willingness to accept demand shifting in both groups (1="not important" to 5="extremely important", N=1,084)**

| Decision factors | Willing | Unwilling |
|---|---|---|
| Electricity savings | 4.55, σ=0.67 | 3.94, σ=0.94 |
| Service is performed in due time | 4.21, σ=0.78 | 3.96, σ=0.94 |
| Environmental benefits | 4.20, σ=0.84 | Non applicable |
| Interference with household activities | 3.87, σ=0.95 | 3.75, σ=1.06 |
| Security of electricity supply | 3.79, σ=0.96 | Non applicable |
| Presence of householders at home | 3.09, σ=1.20 | 3.59, σ=1.17 |

**Table 7. Potential behaviours to be adopted in face of a future hypothetical scenario with an hourly change of the electricity price (1="very unlikely" to 5="very likely", N=1,084)**

| Decision factors | Mean | σ |
|---|---|---|
| Shifting loads to cheaper periods | 4.29 | 0.75 |
| Use of enabling technologies | 3.72 | 0.95 |
| Paying attention to electricity prices | 3.27 | 1.09 |
| Invest in decentralised renewable energy sources | 2.84 | 1.14 |
| Accept shifting performed by the utility | 2.41 | 1.19 |

**Table 8. Decision factors influencing willingness to accept direct load control from the utility in both groups (1="not important" to 5="extremely important", N=1,084)**

| Decision factors | Willing | Unwilling |
|---|---|---|
| Risk of damaging appliances | 4.73, σ=0.55 | 3.59, σ=1.21 |
| Electricity savings | 4.69, σ=0.57 | 3.65, σ=1.14 |
| Trust in the utility | 4.46, σ=0.73 | 3.66, σ=1.17 |
| Override option | 4.54, σ=0.71 | 4.37, σ=0.92 |
| Privacy issues | 4.48, σ=0.82 | 4.45, σ=0.82 |
| Provision of feedback (e.g., control actions, savings) | 4.42, σ=0.71 | 4.29, σ=0.91 |
| Pre-existing agreement and prior notice | 4.35, σ=0.76 | 4.28, σ=0.95 |
| Environmental benefits | 4.28, σ=0.82 | Non applicable |
| Risk of interference with household activities | 4.11, σ=0.11 | 4.20, σ=0.92 |
| Security of electricity supply | 3.99, σ=0.98 | Non applicable |

## Table 9. Questions included in the survey

<table>
<tr><th colspan="2">COMPONENTS</th><th>QUESTIONS</th></tr>
<tr><td rowspan="6">Characterisation of the case study</td><td>Socio-demographic characteristics</td><td>Gender (F/M); Age; Marital status (single, married, divorced, widower); What is your education level? (none; primary school; high school; secondary school; college and university) What is your main activity? (professional activity; looking for the 1st job; unemployed; working-student; retired; student; no activity; no paid worker) What is your profession? (open answer) What is your current activity? (open answer) What is your employment status? (working for someone else; non-paid worker; employer of less than 10 workers; employer of more than 10 workers; entrepreneur; other)</td></tr>
<tr><td>Geographical location</td><td>What is your postal code?</td></tr>
<tr><td>Energy behaviours</td><td>How often do you perform the following actions: switching off the lights in empty rooms; insulating windows and doors; keeping doors and windows closed when they are being warmed or cooled; switching on heating/cooling equipment only on occupied rooms; switching off appliances using central plugs to avoid stand-by consumptions; switching off appliances directly on the switch to avoid stand-by consumption; switching off TV when nobody is watching it; switching on washing machine/dryer during the cheapest periods; talking with the dwelling occupants about electricity consumption and savings; reading the electricity bill; providing the meter readings to the electricity supplier; buying more energy efficient equipment.</td></tr>
<tr><td>Personal determinants</td><td>Do you agree with the following statements - "Saving electricity…" improves the environment; …improves the national economy;…improves the power grid management;…contributes to minimise energy imports;…begins with my example;…is a society obligation;…is a consumer responsibility;…represents economic advantages to the household;…implies a lifestyle with reduced comfort;…brings too much disturbances to my lifestyle than the generated benefits;…disturbs the household daily activities;…spends too much of my time.</td></tr>
<tr><td rowspan="2">Influence of economic crisis on energy behaviours</td><td>Has your electricity use changed because of the current economic crisis? Yes/no. If yes, how? we have reduced the use of some appliances; we began reading the bill or the meter; we changed the contracted power; we changed the tariff; we began turning some equipment on during the cheapest period; we bought more efficient appliances; we improved the dwelling in order to save; we invested in renewable energy sources; other</td></tr>
<tr><td>If no, because: we haven't yet felt the need to save electricity; we already save as much as we can; there are limitations preventing us from saving more; other</td></tr>
<tr><td rowspan="4">Energy behavioural adaptations during the transition to smart(er) grids</td><td>Adhesion to the liberalised retail energy market</td><td>Have you changed your electricity supplier due to the liberalised market? (If no) Why? Prices are not interesting; there is no sufficient information; my friends or family advised me not to change yet; I do not trust in energy suppliers; I did not know it was possible to change; I am satisfied with the present service. Do you know the DECO campaign “Together we pay less?” Yes/no. Have you enrolled in this campaign? Yes/no.</td></tr>
<tr><td>Adoption of smart grid technologies</td><td>Do you use any electricity monitoring device (e.g., display)? Yes/no. Do you use any control device to save electricity? Yes/no. (If yes) In which equipment? Washing machine; drying machine; dishwasher; water electric heater; air conditioning; electric heater; other. Are you a prosumer? Yes/no. Do you own an electric/hybrid vehicle? Yes/no.<br><u>In hypothetical future scenario of dynamic pricing of electricity</u>, what level of importance would you give to the functionalities of an automated device to manage electricity use? Real time information on consumption, cost and savings; information on controlled appliances; turning off stand-by; turning off appliances; automated shifting to cheaper periods; automated alteration of appliances settings to reduce electricity consumption. Would you be interested in adopting an automated device to manage your electricity use? Yes/no. (If yes) How important are the following adopting factors: trust in the technology; low cost of acquisition; level of electricity savings; user friendly; functionalities; ease of installation and configuration; quality of the feedback; design; not damaging equipment; full control over the device.</td></tr>
<tr><td>Flexibility for demand shifting and change the household routines</td><td>Would you be willing to switch your appliances on in a different schedule than the usual? Yes/no. (If yes) How important are the following factors? Effective electricity bill savings; environmental advantages; only if each appliance concludes the cycle at the intended hour; only if it does not interfere with the household activities; To be at home when appliances are switched on. (If no) How important are the following factors? Appliances must be switched on at the schedule I establish; being at home when appliances are switched on; level of electricity bill savings; guarantee appliances conclude the cycle at the intended hour; not interfering with the household activities.<br>Please indicate your flexibility to change the time-of-use of the following appliances: washing machine; drying machine; dishwasher; water electric heater; air conditioning; electric heater.<br><u>In hypothetical future scenario of dynamic pricing of electricity</u>, would you admit changing the way you use electricity? Yes/no (If yes) How likely would you adopt the following practices? I would pay attention to electricity prices at each moment; I would shift my demand to cheaper periods; I would invest in decentralised renewable energy sources; I would install automated control devices do shift my demand; I would accept load control performed by the electrical utility. (If no) Why? Prices variation would not significantly change the electricity bill; I do not have the possibility to significantly shift my electricity demand; I would be afraid to damage equipment; it would generate more inconveniences than advantages; I believe that scenario is a manipulation exercise by the utility.</td></tr>
<tr><td>Willingness to accept load control</td><td>Would you be willing to accept the control of some appliances by your electricity utility? Yes/no. (If yes) How important are the following factors? Only if needed to ensure electricity supply; only if it was established in the contract and there was a previous warning; trust in the utility; possibility to override, at any time, that control; effective electricity bill savings; environmental advantages; not interfering with the household activities; not compromising privacy; be informed of the control actions and savings generated; not damaging equipment. (If yes) How willing are you to accept the following control actions over these appliances: shifting to a cheaper period (washing machine; drying machine; dishwasher; water electric heater); turning off for small instants during the most expensive periods (water electric heater, fridge or freezer; air conditioning); changing the temperature set-point during the most expensive periods (water electric heater, fridge or freezer; air conditioning). (If no) How important are the following factors? Interference with privacy; Mistrust in the electricity utility; Unawareness on the motive requiring that action; Risk of damaging equipment; Risk of inference with the household activities; Lack of contractual legitimacy; Unawareness on the control actions; Reduced electricity bill savings; No override function.<br>Do you own an air conditioning system? Yes/no. (If yes) How to you use it? I keep it switched on at a constant temperature set-point; I switch it on temporarily to cool or heating a room; I never switch it on.<br><u>In hypothetical future scenario of dynamic pricing of electricity</u>, how willing are you to accept the following control actions over these appliances: shifting to a cheaper period (washing machine; drying machine; dishwasher; water electric heater); turning off for small instants during the most expensive periods (water electric heater, fridge or freezer; air conditioning); changing the temperature set-point during the most expensive periods (water electric heater, fridge or freezer; air conditioning).</td></tr>
</table>

## LIST OF FIGURES

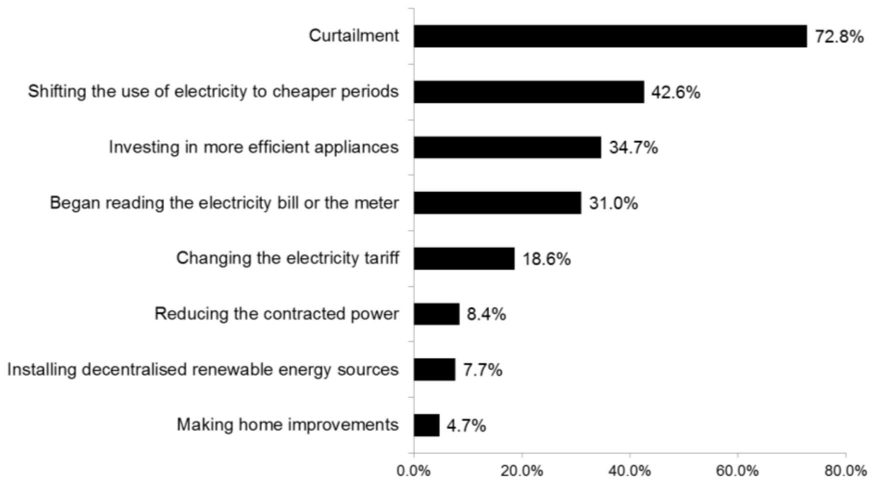


**Figure 1 - Energy behaviours changes due to the economic crisis**


**Figure 2 - Barriers for not joining the liberalised retail energy market**

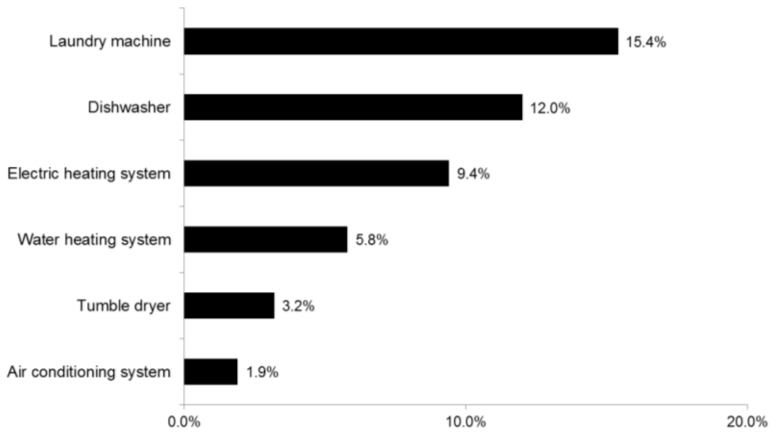


**Figure 3 - Appliances controlled by respondents**

## Highlights

- Energy behavioural adaptations during the transition to smart grids are explored
- A web-based survey was performed to a representative sample of Portuguese consumers
- Users are prone to adopt smart technologies and shift demand rejecting load control
- Preferences for adopting a demand-responsive energy management system are assessed
- Factors influencing behavioural adaptations are analysed and strategies proposed