






Assessing Household Electricity Consumers' Willingness to Load Shift

Paula Ferreira^(✉) , Ana Rocha , and Madalena Araújo 

ALGORITMI Research Center, University of Minho, Guimarães, Portugal

paulaf@dps.uminho.pt

Abstract. This paper focuses on the acceptance and motivations towards load shifting programs in the household sector. The research is based on a questionnaire addressing the Portuguese population and aiming to better understand the willingness to engage in load shifting, the main motivations for this, and the acceptance of automatic control systems to improve responsiveness to prices changes. The willingness to load shift electricity was then assumed as a proxy for the availability of the respondents to engage in a demand response (DR) program. The results show that most respondents would consider the engagement in DR and that the economic benefits are still the main driver. However, environmental concerns and even contribution towards reducing importations for the country emerge also as important motivations in particular for younger respondents. The study concludes also on the need to improve communication on DR programs and overcome the consumers' inertia that still exists and prevent more effective participation in the electricity market.

Keywords: Demand response · Survey · Portugal · Flexibility · Consumers' inertia

1 Introduction

The energy supply grid system is currently undergoing a transition from a centralized and non-participating end-user model towards a decentralized and highly participative model. The former is mostly associated with non-renewable and fossil fuel supply, while the latter has been increasingly related to a greater share of renewable energy supply across the world and by the increase of small-scale energy producers. This entails a significant change in pre-existing models as consumers become also energy producers, i.e. transition to prosumers status as agents that both consume and produce energy [1]. Although this will create new opportunities for consumers to participate in electricity markets, the abovementioned change is characterized by the increasing concerns over intermittency and increased grid complexity, which poses a challenge in meeting a balance between the supply and demand sides. Among the challenges associated with this new energy supply model, is that the potential burden costs have to be ensured by the final consumer through the energy bill. The envisioned solutions to overcome these challenges are based

on technological progress and innovation, as well as improved communication systems that enable the deployment of smart grids. Fostering the development of Smart Grids could facilitate the transition from a traditional to a new model: (i) removing of existing barriers between the energy producers and end-users, thereby establishing microgrids; and (ii) through Demand Side Management (DSM), which comprises energy efficiency, energy storage, and Demand Response (DR) strategies. DSM aims then to implement amendments in demand for electricity through different measures such as providing better and on-time information about electricity tariffs or changing the existing tariff structure [2], promoting the use of smart devices (e.g. smart meter), thereby supporting the end-users on the energy management [3] and reducing overall energy demand.

In a power system, the demand side was a huge potential for flexibility requirements and have an important role in the transition towards renewable energy systems [4]. The flexibility potential is uncertain, once their potential is mainly affected by the consumer energy behaviour, i.e., if the consumers are willing to shift their energy usage from peak (high price) to off-peak period (low price) [5]. However, to increase the flexibility is remarkably necessary a massive investment in a new power system. As an example, heat pumps that connected with the district heating system and heat storage could promise flexibility [6], the Electric Vehicles (EVs) through of charging and discharging of their battery, could be used as a flexibility source, in which the V2G (Vehicle to Grid) technology enables the end-user to manage the electricity use, charging the vehicle in off-peak hours, storing the energy to be used at peak times [7]. Another relevant option to benefit from the consumers' flexibility is the DR that usually is related to changes in energy consumption behaviour to respond to the changing of prices.

According to Federal Energy Regulatory Commission (FERC), DR can be defined as "Changes in electric usage by end-use customers from their normal consumption patterns in response changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" [8].

In particular, the potential benefits of DR can be felt on both demand and supply sides: (i) end-users (demand side), allowing to reduce the electricity bill providing financial incentives to the consumers for reducing electricity consumption, when the price is high, or shifting the electricity consumption to off-peak hours; (ii) electricity market operator (supply side), providing several options for grid and electricity cost management and the system operators making the system more capable to meet contingencies [9]. As [10] stated, DR is a valuable tool to provide flexibility to the power system, to support the integration of Variable Renewable Energy resources and to manage the grid. Shifting or reducing the demand for electricity during peak hours can contribute to improving the grid, but according to [11] the potential benefit has to be enough to encourage the consumers to shift their electricity usage. The results of [4] also point to important societal benefits but modest consumers savings related to DR programs and underline the need to consider additional policy measures. In addition to the issue of private economic benefits, [1] call attention to the social and behavioural aspects of energy decision making including the reduced interest on the topic or even concerns related to privacy and sharing of data.

This paper contributes to add to the state-of-the-art by addressing the social awareness, acceptance and motivations towards DR programs. This research used a combination of literature review and questionnaires to explore the willingness to participate in these programs, main motivations factors and to estimate the consumers' flexibility. The empirical research method focused on DR programs and target the Portuguese household consumers, assessing in particular (i) the motivational factors to shift the electricity use (ii) the willingness to participate in load shifting programs (iii) the willingness to accept the automatic control of the heating and cooling system. For this study, willingness to shift electricity use was then assumed as a proxy for the availability of the respondents to engage in a DR program.

The central research questions associated with this paper are:

Are the electricity consumers willing to participate in some load shifting activities?
Which motivational factors may trigger the acceptance of the shifting of electricity use?
Are the electricity consumers willing to accept the automatic mode of the heating and cooling system to respond to electricity price changes?

The remainder of this study is organized as follow. The following section presents an introduction to household energy use in Portugal. Then, Sect. 3 presents the research method applied in this study. Section 4 discloses the results and their discussion, and Sect. 5 presents the conclusions of this paper.

2 Household Energy Use in Portugal

The electricity consumption of the household sector in Portugal still lags behind the industrial and tertiary sectors, but even so, it represents close to 27% of the total demand in 2019 (source www.dgge.pt, consulted September 2021). Electricity plays a fundamental role in household activities and according to the last survey on energy consumption in households, published in 2020, electricity is the main source of energy consumed in households representing 46.4% of the total energy consumption against 42.6% in 2010. The report demonstrates the increasing importance of electricity for the household sector, related to the increasing demand for comfort and the growth of electricity appliances [12]. However, biomass is still the dominant heating system which can affect the consumers' sensitiveness to electricity price changes. For example, [13] argue that rural households in Portugal are more sensitive to price changes than urban ones and this may happen because rural populations can more easily use biomass for heating or even cooking.

As [14] recalls, electricity tariff price structures should always be borne in mind the supply marginal cost to foster the efficient use of electricity and the recourses involved in the value chain of the power system. Namely, the production marginal cost differs from hour to hour, during the month or even throughout the year, motivated by the different cost functions of the entire value chain of the power system, production, system, distribution, distribution, and retail. Another relevant point is that the demand is stochastic, this will have repercussions on production cost that could be vastly affected by external factors such as changes in fossil fuel prices and weather conditions [14].

In Portugal, the electricity tariff can have different values, depending on the time-frame and different seasons (summer and winter periods). Time schedules for the free

time-of-day tariff intervals and tariffs for the last resource supplier are determined once a year by the regulator (ERSE) for the coming year [14]. Therefore, considering the aforementioned background, different time-of-day tariff schemes are available to the consumers (e.g. weekly vs daily). The last regulation published by ERSE [15] established the following intervals for the daily scheme for the household low voltage consumers:

- (i) Low – period of low electricity consumption and low price corresponding to 4 h/day;
- (ii) Full – period of high electricity consumption and high price corresponding to 10 h/day;
- (iii) Peak – period of very high electricity consumption and very high price corresponding to 10 h/day.

The possibility of dynamic tariffs is also being considered in this regulation, although still focusing on industrial consumers.

3 Research Method

3.1 Survey Design and Implementation

Data was collected by a company specialized in CATI (computer-assisted telephone interview). The sample was randomly taken from 278 municipalities, in geographic terms, the above analysis only considers Continental Portugal (i.e. excluding Azores and Madeira Islands). The questionnaire was drafted in Portuguese, and the time taken for answering all questions reached about five minutes.

For the preparation of the questionnaire, an analysis of the household electricity consumption and the tariff was conducted as described in the previous section. To define the final questionnaire's formats a pre-test was conducted using a face-to-face approach with a small group of residential electricity consumers. This pre-test enabled us to get a better feel of the difficulties the respondents could have in understanding the vocabulary used and the time needed to fill the questionnaire. Lastly, a pilot project with university students through web-survey was conducted to evaluate their electricity perception about electricity use and refine the questions [16].

The survey was conducted during May and June of 2018. To ensure at least a confident interval of 95%, with a marginal error of 5%, the sample size was calculated using the Eq. (1).

$$s = \frac{Z^2 \times (p) \times (1 - p)}{c^2} \quad (1)$$

where z is equal to 1.96 (since the confidence level is 95%); p is a percentage picking a choice, expressed as a decimal (in which, 0.5 was used for the sample size needed) and c is the confidence interval (5%) that needed to be expressed as a decimal (0.05).

3.2 Survey Description

The questionnaire included four parts:

- Part I, related to sociodemographic characteristics of respondents and included 5 questions concerning gender, age, education, professional activity and household size.
- Part II, addressing the issues related to consumers inertia/knowledge about electricity use and bill, and included 4 questions addressing regularly reading the electricity consumption on the meter, actively looking for different electricity suppliers, awareness about ToU tariffs and ownership of electricity monitoring devices.
- Part III, on possible motivational factors to engage in DR programs, with 4 questions addressing environmental, cost, country importations or acquaintances advice. If the respondent was not interested in participating in DR programs, a fifth question was asked about the motivations for rejection.
- Part IV, on flexibility on electricity use, with 1 question about the possibility of engaging in an automatic control program for the heating or cooling system.

The respondents were asked about their agreement with some presented sentences. This agreement was measured by the scale “totally disagree”; “tend to disagree”; “tend to agree”; “totally agree” and “does not know/does not answer”. A summary of the statistics regarding the respondents’ sociodemographic characteristics is presented in Table 1.

The sample is composed of 410 respondents, of which 225 female and 185 male. Results on educational characterization show that 38.8% of the respondents have a higher education level (university), while about 34.4% of the respondents have studied less than 12 years in school. About 64% of the respondents are aged between 25 and 64. The majority of respondents is engaged in professional activity (53.7%), of which about 10% are self-employed. The remaining respondents are students (4.6%), retired (27.3%), unemployed (10.3%) or households (4.1%). The average household size (number of occupants) is approximately 2.7. The majority (52.73%) of the respondents claimed that their monthly electricity bill would be in the range of 26 €–55€ and only 2.6% of the respondents claimed to pay more than 150 €/month.

After collecting the data a descriptive analysis was performed employing the Fisher’s exact test and Chi-square test. These tests were used according to the nature of the variables and based on the methodologies described in [17]. Results were considered statistically significant when the p-value was less than 0.05. Statistical analysis was conducted using the software STATA 15.1.

Table 1. Sociodemographic characteristics of respondents

	N	%
Gender		
Male	185	45.12
Female	225	54.88
Age		
18–24	38	9.27
25–44	136	33.17
45–64	128	31.22
Above 65 years old	108	26.34
Education		
No education	4	0.98
4 th grades of school	53	12.93
6 th grades of school	44	10.73
High school	40	9.76
Secondary school	110	26.83
Graduate or bachelor	125	30.49
Master's degree	33	8.05
PhD	1	0.24
Professional activity		
Unemployed	42	10.24
Student	19	4.63
Posted worker	179	43.66
Self-employed worker	41	10.00
Retired	112	27.32
Domestic (stay-at-home)	17	4.15
Household size		
1 member	54	13.17
2 members	145	33.37
3 members	119	29.02
4 members	65	15.85
5 members	19	4.63
Above 5 members	8	1.95
Monthly electricity bill value		

(continued)

Table 1. (continued)

	N	%
DA – 25€ or less	30	7.79
DB – 26€–55€	203	52.73
DC – 56€–100€	118	30.65
DD – 101–150€	24	6.23
DE – more than 150€	10	2.60
Urban/Rural		
Urban	268	65.37
Rural	142	34.63

Note: the attribution of rural and urban classification for each parish is based on (PRODER, <http://www.proder.pt/>). A municipality is considered rural or urban if 50% of parishes are included within the former or the latter category. Hence, the predominance of the rural category (>50%) implies a rural “concelho” and vice-versa.

4 Results and Discussion

This section is divided into three subsections according to the structure of the questionnaire.

4.1 Consumers Inertia and Knowledge on Electricity Consumption

After collecting the data about sociodemographic characteristics, the respondents were asked about their knowledge about time of use (ToU) tariffs, in which the terms “*bi-horário*” (two-tier tariffs) and “*tri-horário*” (three-tier tariffs) were used to facilitate a better understanding of the respondents. For this question, respondents were presented with two options “yes” or “no” to assess whether the respondents were familiar with these terms. To assess the inertia of the respondents three proxy questions were formulated:

- Do you regularly communicate (around every two months) the reading of your electricity meter to your electricity supplier?
- Have you changed to another electricity supplier in the last two years?
- Do you own/use any electricity monitoring device (other than the electricity supplier meter)?

The options for answering these three questions were “yes” and “no”. Figure 1 summarizes the obtained results.

According to the results, about 85% of the respondents are familiar with the ToUs tariffs. Over half of the respondents regularly communicate their electricity consumption to the electricity supplier, and 22.2% of them showed to be proactive in switching electricity suppliers. However, only a minority of the respondents (about, 11.1%), indicate that they own an electricity monitoring device.

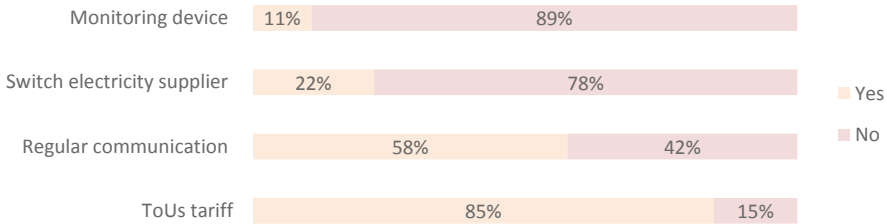


Fig. 1. Knowledge and inertia of the respondents

Using Fisher's exact test, the results indicate that gender seems not to be statistically correlated to all these four questions: familiarity with ToUs tariffs ($p = 0.891$), regular communication ($p = 0.548$), switching electricity supplier ($p = 0.282$) and ownership of monitoring device ($p = 0.543$). This suggests the inertia and the knowledge of the respondents are not correlated with gender.

To understand the extent of the significance of age on the knowledge and inertia of the respondents, the Chi-square test was used. The results showed that the respondents between 25 and 44 years old are better-informed about ToUs tariff ($p = 0.004$). The respondents included in this category also tend to indicate that they communicate regularly the reading of the electricity meter to the electricity supplier ($p = 0.018$). This is not an expected result, given that these respondents categories tend to be in charge of electricity bill payment [18]. Although the ownership of smart meters was in general limited, age is statistically significant with young participants showing higher ownership rates (between 18–24 years old, $p = 0.000$). As expected, technology acceptance is correlated with age [19]. However, according to the Chi-square test, age does not seem to be correlated to the interest in switching electricity suppliers ($p = 0.422$).

The Chi-square test showed that the education level is statistically significant for familiarity with ToUs tariffs ($p = 0.012$), regular communication of the reading of the electricity meter ($p = 0.025$) and ownership of the monitoring device ($p = 0.001$). In general, the respondents with a high educational level tend to be more well informed and active. However, once again the variable education is not statistically significant for switching electricity supplier ($p = 0.415$).

Using the Chi-square test, it is possible to state that the professional activity of the respondents is associated with the knowledge and the inertia ($p_{\text{ToUs tariff}} = 0.015$; $p_{\text{Regular communication}} = 0.025$; $p_{\text{monitoring device}} = 0.001$), while again not statically significant for the case of switching of electricity supplier. Nevertheless, some important trends can be drawn: respondents whose professional activity can benefit from spending more time at home, such as, retired, domestic or unemployed, tend to be less active and less well informed.

This study also takes into consideration the level of electricity consumption between the rural and urban areas. Using Fisher's exact test, it is possible to conclude that people who are living in urban areas are more prone to regularly communicate electricity consumption to the supplier. This finding is in line with [20], as the authors suggest that in urban areas the chance of success to implement DR is higher due to higher population density and higher energy and environmental concerns.

4.2 Motivational Factors for Load Shifting

In the survey, respondents were also asked about their motivation to shift electricity usage. To address this, the respondents should answer using the scale “totally disagree”; “tend to disagree”; “tend to agree”; “totally agree” and “does not know/does not answer” whether they are willing to shift their daily electricity usage: (1) to contribute to benefit the environment, (2) to contribute to reducing the dependence on imported energy, (3) to reduce their electricity bill or (4) to follow acquaintances advice.

Only 6% of the respondents were not willing to shift their electricity use for whatever motivational factor. When asked about the main reasons not to make, the principal motives reported were the possibility of reducing the comfort of the household (32%) and lack of time (24%). Two other important reasons were mentioned: the feeling that they were not well-informed on the theme (16%) and believing that shifting electricity consumption will not be enough to reduce significantly the electricity bill (20%).

However, an overwhelming majority (94%) of the respondents show some degree of willingness to shift the electricity use. As shown in Fig. 2, the reduction of the electricity bill is a determinant factor for respondents to shift their electricity usage. This result suggests that the monetary benefits would be key to deploy the DR programs as debated in other studies [21, 22]. In addition, a large percentage of respondents said that they “totally agree” or “tend to agree” to shift the electricity usage whether it would benefit the environment (66%) or reduce the percentage of imported energy (61%). It is also interesting to notice the social effect measured by the recommendations seems to play a less important role in the decision-making process of the participants.

Using the Chi-square test it was possible to conclude that the environmental factors are statistically associated with the education level ($p = 0.001$), and professional activity ($p = 0.003$). This result suggests that people with a high level of education and students tend to be more aware of environmental problems. Younger respondents ($p = 0.001$) are more willing to shift their electricity usage if it benefits the environment. This result demonstrates that the variable “environmental factors” may contribute to boosting DR programs and associated technologies, as discussed in a survey sponsored by the Eurobarometer [23]. This report [23] concluded that the majority of the European respondents (35%) agree that a potentially effective way of tackling environmental problems is investing in research and development to find technological solutions. It should also be noted that the variable “gender” is not statistically significant for any of the motivational factors (environmental; reducing energy imports, reducing the electricity bill and recommendation).

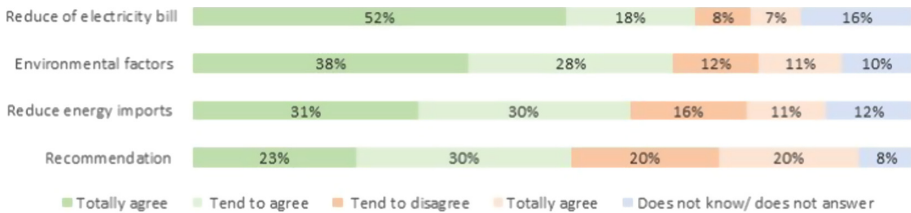


Fig. 2. Motivational factors to shift electricity usage

As for the cost savings motivation, the Chi-square test indicated statistical significance to the education level ($p = 0.044$) and professional activity ($p = 0.000$). People with higher education levels and domestic are more willing to shift their electricity usage to reduce the bill. The same also goes for age, as respondents aged between 24–44 years old ($p = 0.000$) are more willing to shift their electricity usage.

4.3 Flexibility on Electricity Use

In the survey, participants were also asked whether they would accept the automatic adjustment of the heating or cooling system to respond to higher electricity prices. This question aimed to assess the willingness to participate in a future dynamic tariffs scheme.

The results presented in Fig. 3 indicate that more than half of the respondents are willing to accept some automatic control system. Nevertheless, there is a significant share (24% of respondents) who answered, “does not know/does not answer” or that “totally disagree” and “tend to disagree” (17%). This result suggests that the respondents feel that they are still not well-informed of the potential benefits, of the mechanisms to implement this system or may even have concerns about data privacy.

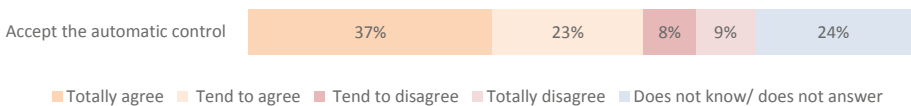


Fig. 3. Willingness to accept the automatic control of the heating or cooling system

The statistical tests indicate that the sociodemographic variables do not influence the willingness to accept the load control (p -value > 0.05). However, the Chi-square showed that the value of the electricity bill of the respondents is statistically significant (p -value = 0.022), suggesting that the value that respondent’s survey pays for the electricity encourage them to accept the automatic control of the heating cooling. Namely, respondents paying higher electricity bills are more open to accepting this automatic control system.

5 Conclusions

Using a large, nationally representative sample of 410 household respondents, this work aims to contribute to better understand the public acceptance of possible DR programs, possible concerns and main motivational factors. In general, Portuguese citizens are well informed about ToUs tariff. A large share (85%) of the respondents are aware of the possibility of switching from flat rate to ToUs tariff. Moreover, most of the energy consumers would consider the possibility of engaging in some load shifting scheme. Only 6% of the consumers refused the idea of shifting their electricity use and this was mainly due to concerns related to household comfort. The lack of information to make a decision is also mentioned by the respondents and reflects an important barrier for DR uptake.

The results indicate that the economic incentives still play a decisive role in the consumers' decision-making process. This is particularly evident for respondents with higher education levels and staying at home (domestic). However, the results also show that the retired and domestic groups are the less active ones on changing electricity suppliers and tend to be less informed about ToU tariffs. The environmental factors and contribution for reducing the dependency on energy imports are also significant for the decision to shift electricity use. The results confirm that younger respondents tend to be more sensitive to these environmental aspects. This shows the importance of designing information campaigns directed towards different consumers and acknowledging their different concerns and motivation. This should also contribute to overcoming the low consumer awareness or interest to participate in the electricity market.

The majority of the respondents would be willing to accept the automatic control for the heating or cooling systems. This result suggests that the automatic mode should be considered in the development of DR programs. There is still a lot of undecided consumers which once more calls for additional information to reduce the consumers' inertia and increase their trust in the system.

The results of this work could provide important insights for energy policies and energy companies to design policies and strategies towards the development of future power grids and influence the final consumers to be more flexible. For this, future work should address the range of the energy flexibility as this may be limited by the building characteristics [24], socio-economics conditions and everyday routines [25]. Moreover, new DR programs well fitted to different consumers should be established along with effective communication strategies.

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